CARIES DIFFERENCES AMONG SUB-SAHARAN AFRICANS

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A

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ABSTRACT

Teeth are a vital source of data for interpreting ancient lifestyles because of their high preservation potential and direct association with food. Understanding dental pathologies such as dental caries (cavities), can provide valuable information regarding diet and health. The objective of the present study is to compare caries prevalence among sub-Saharan African populations to determine whether any significant differences exist through space, time, economy, and between the sexes. A few small-scale dental pathology studies have been undertaken on specific populations and regions, but until now none have encompassed the entirety of sub-Saharan Africa from the Late Stone Age through modern times. Data on caries counts and severity from 1963 individuals comprising 44 sub-Saharan samples are compared using Mann-Whitney U and factorial ANOVA statistics. Results suggest: 1) major changes in diet related to widespread movement of people caused a general increase in caries; 2) there is no statistically significant difference in the frequency of caries between males and females; 3) people living in the savanna have more caries because of their dependence on high carbohydrate foods; and 4) subsistence strategy plays a role in caries frequencies. These findings reveal that global trends in caries susceptibility as described by other researchers do not always apply and that each population should be considered in turn.

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CHAPTER 1: INTRODUCTION

The objective of the current project is to determine whether caries frequencies differ between time periods, sexes, environmental settings, and subsistence strategies among a large number of sub-Saharan African population samples. Sub-Saharan Africa represents an immense area filled with many diverse groups of people. A few limited studies have been undetaken to look at dental pathologies from specific areas but none consider the entirety of sub-Sahara Africa from the Late Stone Age through modern times.

Inferring diet from archaeologically-derived remains is often difficult, especially when taphonomic processes have destroyed the bulk of the data. Frequently researchers are left with only the most resilient of materials such as stone, bone, and teeth upon which inferences about ancient lifestyles may be based. Understanding how these materials are used and how they are affected by human behavior is vital for piecing together the puzzle of human history.

Teeth are particularly important sources of data for reconstruction of prehistoric diets because of their high preservation potential and because of their direct association with food. Dental pathologies provide information on diet, stress, and cultural practices. More specifically, a comparison of dental caries (cavities) among individuals can highlight dietary differences and trends among groups. Sugar and starch intake, the adoption of agriculture, and behavioral and biological differences between the sexes and among populations have all been found to influence dental decay (Turner, 1979; Newbrun, 1982; Larsen, 1997; Lukacs and Largaespada, 2006; Lukacs and Thompson, 2008).

Data on caries prevalence and severity from 44 samples (1,963 individuals) throughout sub-Saharan Africa have been collected and will be compared using Mann-Whitney U and factorial analysis of variance. The samples date from 10,000 BP to modern times and are divided into three broad time periods: the Late Stone Age, Iron Age, and Recent. Mann-Whitney U tests are used to compare the categories within each variable for any significant differences in caries frequencies. In addition, the factorial ANOVA statistic is used to observe if any of the four variables considered (sex, environment, subsistence strategy, and time) significantly influence caries rates. Results are discussed in terms of diet and other cultural practices that are known to affect dental health.

1.1 Research Questions

The study lends itself to four research questions:

1. Did caries frequencies change through time? For the purposes of the current study the samples have been divided into three time periods: Late Stone Age, Iron Age, and Recent. Each time period is marked by a drastic change in diet as new foods were introduced and other foods were removed.

2. Is there a difference in dental decay between the sexes? The literature indicates a global trend for higher caries frequencies in women, especially with the advent of agriculture (Caselitz, 1998; Lukacs and Laraespada, 2006; Lukacs, 2008; Lukacs and Thompson, 2008; Ferraro and Vieira, 2010). The results from this study will test whether the trend holds true for sub-Saharan Africans.

3. Are there environmental differences in the frequency of caries throughout sub-Saharan Africa? Caries occur primarily as a result of diet which is determined by what foods can be grown or otherwise obtained. Environmental factors limit what foods are present and thus might be a factor in dental decay. Individuals are divided based what ecosystem they lived in: coastal, desert, savanna/grassland, and tropical rainforest.

4. Does subsistence strategy affect dental health? Sub-Saharan Africans practice a variety of strategies to collect food including hunting and gathering, pastoralism, and agriculture. Because diet was determined by subsistence strategy there might be some impact upon rates of dental decay.

1.2 Hypotheses

To determine whether there are significant differences in caries prevalence across samples, a hypothesis is tested using Mann-Whitney U and factorial ANOVA statistics.

1. *Null Hypothesis*: There is no statistically significant difference in caries prevalance among the different sub-Saharan environments, time periods, subsistence strategies, or sexes.

2. *Alternate Hypothesis*: There are statistically significant differences in caries counts among the different sub-Saharan environments, time periods, subsistence strategies, or sexes.

1.3 Significance

The present study is significant for three reasons. The first and probably most important of these is its area of focus. Relatively few studies, especially those based on dental anthropology, have been conducted on late- and post-Pleistocene sub-Saharan Africans (Irish, 1993). Despite its rich history and great size, sub-Saharan Africa has been largely overlooked by researchers. In order to fully understand what factors have the greatest impact upon dental health, studies that include large diverse populations from all over the world are needed. This study includes both a large (44 samples) and diverse sample set. There are no other African dental pathology studies that incorporate samples that cover such a extensive time span and such a large area.

Second, any comparative dental work that has been done has either focused on qualitative data (i.e. morphological studies) or has just focused on small populations in either space or time (Flower, 1889; Shaw, 1931; Frencken et al., 1986; Morris et al., 1987; Solanki et al., 1991; Sealy et al., 1992; Mackeown et al., 1995; Steyn et al., 1998; Cleaton-Jones et al., 2000; Ohinata and Steyn, 2001; Pistorius et al., 2002; Steyn, 2003). This study examines dental pathologies from samples all over the sub-continent and includes both ancient and recent samples. Including such a broad assortment of samples can reveal patterns that might not be detectable in smaller studies. Also, in order to make inferences about ancient lifestyles from the dentition, researchers must have complete understanding of the etiology of dental pathologies, especially caries.

Third, the scope of the present study is massive. Any trends that are observed account for a large population and thus can lend credence to patterning observed in other studies. Additionally, results might add clarification to samples/populations that do not meet what is generally considered standard in terms of caries prevalence.

1.4 Organization of the thesis

This thesis has four main objectives including: 1) inform the reader of sub-Saharan Africa's diversity and complex history 2) relate how the study of dental pathologies can inform researchers about ancient lifestyles 3) describe the samples to provide a reference for analysis 4) present the results and discuss how the findings fit in with patterns observed from other populations and how the samples compare to each other. Each of the chapters are described below.

Chapter 2 provides a review of the relevant literature concerning the nature of dental caries. First, a description is given for the field of dental anthropology and its subfield of dental pathology studies. Second, the advantages and disadvantages of studying teeth are discussed.

Third, the causes and factors of dental caries are reviewed, including a brief account of attrition and its relevance to dental caries. The chapter ends with an examination of previous dental pathology studies conducted in the sub-continent.

Chapter 3 provides a summary of sub-Saharan African prehistory and history as well as a description of the samples. The chapter begins with a discussion of the Late Stone Age, the Bantu Expansion (Iron Age), and the post-European contact phases in sub-Saharan history. The relevant samples are reviewed within each of the phases including their diet, location, subsistence strategy, and archaeological context (if relevant). For convenience a table is provided with all relevant information for a quick reference.

Chapter 4 describes the statistical methods used. The methods for determining basic information such as sex and age as well as reasoning for the selected statistical tests are specified.

Chapter 5 includes a series of graphs and tables to display results from calculating the percentages of teeth infected with caries and results from Mann-Whitney U, factorial ANOVA, and Spearman's Correlation Coefficient. A brief explanation of the results is given.

Chapter 6 is an in-depth discussion of what the results imply. Each of the research questions is discussed in turn. The outcomes are compared with other analyses from around the world to help explain patterns or lack of patterns.

Finally, Chapter 7 presents a summary of the research and findings. Possible future work concerning the data and similar analyses are also considered.

CHAPTER 2: METHODOLOGICAL BACKGROUND

2.1 Dental anthropology

Dental anthropology is the study of people by means of their dentition. Because of the many benefits of studying the dentition (see below), dental anthropology has become an important subfield of biological anthropology in regards to human affinity, health, diet, environment, and behavior. Dental morphological, metric, and pathologic studies are essential for understanding past and living populations.

2.2 Advantages to studying teeth

There are many advantages to the study of teeth. Perhaps the most relevant and important fact for archaeologists and paleoanthropologists is that teeth are resilient and are more likely to survive taphonomic processes than any other biological component of the body (Kelley and Larsen, 1991; Hillson, 1996; Alt et al., 1998). Second, as a result of teeth being exposed in the oral cavity both living and past populations can be studied without excessive costs (Kelley and Larsen, 1991; Alt et al., 1998). Third, teeth can provide clues to diet and behavior because they come into direct contact with anything put in the oral cavity (Hillson, 1996; Alt et al., 1998). Fourth, teeth do not remodel. Consequently, life histories and behaviors can be observed (Kelley and Larsen, 1991; Alt et al., 1998). Finally, the high genetic component and slow evolution of teeth make them well-suited for affinity and evolution studies (Kelley and Larsen, 1991; Alt et al., 1998).

2.3 Disadvantages to studying teeth

Even with all of the benefits of studying teeth there are some obvious drawbacks to the field. First and foremost, information concerning morphology, metrics, and pathology can be lost through disease, ante-mortem tooth loss (AMTL), and post-mortem tooth loss. Second, there is a major lack of standardization in recording dental information (Turner et al., 1991; Hillson, 1996). There are several different recording systems and many are incompatible with one another which makes it difficult to combine samples from different studies. Thirdly, teeth are very complex and their modes of genetic inheritance are relatively unknown; lack of such knowledge can hinder population studies (Hillson, 1996).

2.4 Dental pathology

Dental pathological studies focus on the cause, type, and course of dental diseases and provide valuable evidence concerning diet, age, gender roles, social stratifications, and even cause of death (Lukacs, 1989; Hillson, 1996). Dental caries, periodontal disease, and dental attrition are just a few of the many types of pathologies that can be used to reconstruct life histories. Recording dental pathologies for skeletal remains and living populations is and has been commonplace for anthropologists for years (Hillson, 2001). In examining these diseases, either between or among populations, researchers can begin to reconstruct ancient lifestyles.

2.5 Dental caries

Dental caries are a disease process caused by the demineralization of dental hard tissues such as enamel and dentin (Newbrun, 1982; Larsen et al., 1991). The bacteria *Streptoccocus mutans* and *Lactobacillus acidophilus* consume carbohydrates stuck in the oral cavity then excrete acid that erodes the dental hard tissues (Larsen et al., 1991; Hillson, 1996). Carbohydrates, especially simple sugars (i.e., sucrose), are readily metabolized by the bacteria (plaque) causing a rapid increase in lactic acid (Newbrun, 1982). The acid dissolves the enamel creating a lesion, and with time may even dissolve the dentine exposing the pulp cavity (Hillson, 1979).

Healthy teeth require a balance between acids produced by carbohydrates, and alkalis produced by proteins. In a perfect diet periods of acidity alternate with alkalinity, thus one prevents the dangerous escalation of the other (Hillson 1979). Dental microfloras flourish in the presence of simple sugars such as sucrose, glucose, lactose, and fructose because they are easily digestible. The main instigator is usually associated with sucrose (Hillson, 1979; Newbrun, 1982).

Caries generally progress slowly (chronic caries) or become dormant (arrested caries) but in a few instances can develop rapidly (rampant caries) (Hillson, 1996). Bacteria responsible for tooth decay are commonly located in the pits and fissures of teeth; as a result molars, premolars, and the upper teeth are at greater risk of developing caries (Hillson, 2008). Other factors besides diet and tooth morphology that influence caries are tooth size, enamel defects, attrition, food texture, age, heredity, salivary composition and flow, nutrition, periodontal disease, enamel element composition, and dental hygiene practices (Larsen et al., 1991).

2.6 Factors of dental caries

2.6.1 Diet

In addition to sugar, starches can also cause the number of caries to rise dramatically (Newbrun, 1982; Hillson, 2008). Starches are sticky and allow additional time for the bacteria to digest sugars (Lingstrom et al. 1989, 1993; Larsen, 1997). Caselitz (1998) argues that an increase in potato consumption is a major factor in the rise in caries through time. Starch from the potatoes allows the sucrose to stick to the teeth giving bacteria plenty of time to consume the sugar.

There is some evidence to suggest that an increased amount of protein reduces the risk of caries (Hillson, 1996); however, high protein intake increases the chances of severe calculus (tarter) build-up. Without the acid obtained from carbohydrates extra minerals are deposited on the teeth (Hillson, 1979). There is evidence that people with high protein diets actually have fewer caries. For example, the Inuit, who rely mostly on meat, have a very low invidence of caries when compared to populations with a high carbohydrate intake (Pederson, 1966). Similarly, milk and cheese may prevent dental caries because dairy products coat and protect the teeth from bacteria (Bowen and Pearson 1993; Nase et al. 2001).

2.6.2 Saliva

Saliva also plays an important role in the development of caries. Saliva is produced via three major glands (parotid, submandibular, and sublingual) and coats most of the surfaces in the oral cavity (Ten Cate, 1998; Lukacs and Largaespada, 2006). Saliva is composed of buffering agents, antibacterial agents, and mineralization factors that all function to help prevent dental decay (Lukacs and Laragepada 2006). First, the fluid serves as a defense by washing away debris. Second, it works as a buffer by adjusting pH levels. Finally, saliva contains proteins such as *lysozyme,* which can break down some bacteria, and *lactoferrin,* which binds to iron, an essential element needed by the bacteria (Lukacs and Laragepada 2006). Overall, saliva is essential to keep the oral cavity healthy and any abnormalities or variations in the balance of salivary chemicals can greatly increase the prevalence of dental disease (Leone and Oppenheim, 2001).

2.6.3 Fluoride

Fluoride is another agent that protects teeth from caries (Leverett, 1982; Hillson, 1996). There is a negative correlation between fluoride exposure and caries rates (Russell and Elvove, 1951; Witkop et al., 1962; Leverett, 1982). The intentional introduction of fluoride into most of the world’s drinking water has resulted in a decline in caries frequencies. Fluoride is now a common ingredient in mouthwashes, toothpastes, and is used in standard dental checkups. However, excessive amounts of fluoride may lead to dental fluorosis or mottled enamel (Galagan and Lamson, 1953; Horowitz et al. 1967). Enamel mottling increases with the amount of fluoride present in the drinking water. Optimum amounts of fluoride are generally accepted to be about 1 ppm; lower amounts do not adequately prevent caries and higher amounts might cause fluorosis (Leverett, 1982).

2.6.4 Attrition

The definitions for attrition vary. Where Lukacs (1989) defines attrition as a degenerative dental pathology, Hillson (1996) finds that the lack of wear is the actual pathology, especially in modern populations. Dental wear can be classified into two main categories, attrition and abrasion (Scott and Turner, 1988). Attrition is the natural wear of teeth caused by mastication and is influenced by food texture and preparation (Walker, 1978; Larsen, 1997). Abrasion is the result of foreign bodies other than food in the mouth (Scott and Turner, 1988).

Attrition serves a very important role in relation to dental decay. Consistent wear can aid in caries prevention; dental hard tissues are worn away before plaque can cause any serious lesions (Brothwell, 1963; Scott and Turner, 1988; Hillson, 1996; Caselitz, 1998). Reduced wear commonly associated with agriculture gives time for the bacteria to cause serious damage to the tooth.

The relationship between caries and attrition is difficult considering that increased wear can prevent caries, it can also make teeth more susceptible because of the loss of dental hard tissues. Furthermore, both caries and wear are age-related adding to the confusion when examining the effects of one on the other (Brothwell, 1963). For more information regarding the study of dental attrition, refer to Appendix A.

2.6.5 Genetics

Research has shown that the cause and susceptibility to dental decay is polygenic, meaning that more than one gene is involved (Werneck et al., 2010). In a genome-wide scan, Vieira et al. (2008) found five loci that might affect caries susceptibility. Since the late 1980s, studies have shown that mutations in the AMELX gene can result in amelogenesis imperfecta; this displays the gene's influence in enamel development and potential susceptibility to caries (Lagerstrom et al., 1991; Collier et al., 1997; Deeley et al., 2008; Patir et al., 2008). Slayton et al. (2005) found that the TUFT1 gene combined with high levels of *Streptococcus mutans* greatly increased vulnerability to carious lesions. Pinpointing the genetic cause of dental caries resistance and susceptibility is difficult because of the polygenic nature and all the factors that contribute to caries (Werneck et al., 2010).

2.7 Trends in dental caries

2.7.1 Agriculture

Archaeological data from around the world indicate that caries were relatively rare until the development of agriculture, leading to increased quantities of carbohydrates in the diet (Brothwell, 1963; Turner, 1979; Larsen, 1983, 1995; Caselitz, 1998; Hillson, 2008; Fields et al., 2009). Larsen (1995) also attributes higher rates of dental decay among agriculturalists to the consumption of foods with a gruel-like consistency. Soggy foods are more likely to settle into grooves and fissures so food particles may not be removed by the action of saliva or mastication. In a meta-analysis of caries frequencies among populations with different economies, Turner (1979) found a steady increase in the percentage of teeth with caries relative to the importance of domesticated plants in the diets of foragers (0.0-5.3% caries), foragers/agriculturalists (0.44-10.3% caries), and agriculturalists (2.3-26.9% caries).

Some populations do not show an increased amount of caries with the development of agriculture (Walker and Erlandson, 1986; Larsen 1995; Gamza and Irish; 2012). For example, the inhabitants of the Northern Channel Islands in California exhibit decreasing instances of dental decay even though agriculture became increasingly important (Walker and Erlandson, 1986). This change may be because of a concurrent dependency on marine resources which are high in protein and possibly fluoride (Walker and Erlandson, 1986). Similarly, Tayles et al. (2000) found that rice cultivation may have actually reduced the number of caries in prehistoric populations in Southeast Asia. Rice was eaten unpolished which causes more wear and salivary flow. Generally, agriculture negatively impacted the dental health of populations throughout the world as reflected by increased caries rates.

2.7.2 Sex

Research has found that since prehistoric times, females have been plagued with more caries than males (Caselitz, 1998; Lukacs and Largaespada, 2006; Lukacs, 2008). Several hypotheses have been offered to explain the higher prevalence of caries in females including diet, bacteria amounts, longer tooth exposure, saliva flow and composition, and hormone fluctuations (Lukacs and Largaespada, 2006; Ferraro and Vieira, 2010). Not all populations show a sex bias but it does seem to be the trend in emerging studies (Lukacs and Thompson, 2008).

Some authors argue that diet as a result of gender division of labor is the most probable reason for the difference in caries counts among the sexes (Larsen, 1997; Temple, 2011). Males generally hunt and have more access to non-cariogenic meat, whereas females collect and consume more carbohydrate rich plant foods (Walker and Erlandson, 1986; Larsen, 1997; Tayles et al., 2000; Marlowe, 2010; Temple, 2011). If females were functioning as the primary cooks and collectors then they would have had greater access to carbohydrates, thus increasing the risk for developing caries (Walker and Hewlett, 1990; Tayles et al., 2000).

Walker and Erlandson (1986) have found that diet plays a major role in cariogenesis between prehistoric males and females. Observing caries frequencies from two different samples from the Northern Channel Islands, California, the authors observed that in one of the sites, Skull Gulch, there was no difference in the male and female caries counts. However, at another site, Canada Verde, there was a significant difference between the two sexes. The people of Skull Gulch were found to have a protein-rich marine diet, whereas the Canada Verde people ate more cariogenic foods such as roots and tubers. Because of their reliance on marine species, the Skull Gulch people may also have ingested more fluoride, known to prevent caries (Walker and Erlandson, 1986)

Another potential reason females have more caries may reside in the fact that they have more *Streptococcus mutans* in their mouth (Hillson, 1996; Ferraro and Vieriera, 2010). However, in two studies, Corby et al. (2005) and Loyola-Rodriguez et al. (2008), examining *Streptococcus mutan* levels in opposite gender grade school found no statistically significant difference between the sexes.

Tooth development is more precocious in females relative to males. Hillson (1996) states that a young female’s teeth can look up to 1 year older than the dentition of a male the same age even though female tooth development is only around 3% faster. This suggests that girls’ teeth are exposed to cariogenic foods, bacteria, and the environment for a longer period of time, so as a result, females have more caries than males. Evidence suggests that the few months’ difference is not enough to explain the differences in caries frequencies. Also, as discussed below, adolescent females do not always have higher instances of dental caries (Saravanan et al., 2003; Corby et al., 2005; Loyola-Rodriguez et al., 2008)

Jose and Joseph (2003), in their study of dental health problems in Kerala children, state that there is only a slight difference in the number of caries between 12-15 year-old males (49%) and females (51%). Saravanan et al. (2003) also did a study comparing carries frequency between the sexes using 5 and 12 year-old Indian males and females. In the 5 year-old samples, 47.4% of the males had caries compared to only 41.1% of the females. At age 12 there was a switch; 24.1% of the females were afflicted whereas 20.6% of the males were affected. Earlier tooth development in females is probably not a contributing factor to increased dental decay; otherwise females would always have more caries than males, not just females over 12 years-old. Such studies insinuate that sex differences and bacteria levels do not become apparent until after puberty (Saravanan et al., 2003).

Differences in saliva composition and secretion may also play a role in dental decay. Females are more prone than males to have defects in saliva secretion rates and chemical amounts (Percival et al., 1994; Eliasson et al., 2006). For example, Eliasson et al. (2006) looked at 142 individuals from ages 18-82 and found that females had lower buccal, labial, and stimulated whole-saliva secretion rates than males. In addition, females’ minor glands were also found to have a reduced amount of IgA, an immunoglobulin in the saliva that has been found to protect against caries. The differences are even more obvious in pregnant females (Eliasson et al., 2006).

The hormone premise is much more complex and is not often mentioned as a cause for the uneven caries distribution between the sexes. Experiments on laboratory animals suggests that the most influential hormone involved in cariogenesis is estrogen, the female sex hormone

(Lukacs and Largaespada, 2006; Lukacs and Thompson, 2008). For example, Shafer and Muhler (1954) found that increased estrogen levels in lab mice corresponded to increased numbers of caries. Raising levels of the male sex hormone androgen had no effect. Fluctuating estrogen levels have been shown to have an effect on overall saliva flow rate (Streckfus et al., 1998; Lukacs and Largaespada, 2006). As discussed above, saliva flow has a direct effect on the pervasiveness of caries (Lukacs and Largaespada, 2006). Furthermore, studies have revealed that the biochemical composition of saliva is modified during pregnancy consequently diminishing a female's buffering abilities (Salvolini et al., 1998).

If estrogen is a factor in caries then women are especially at risk during certain times in their lives when hormone levels rise including during puberty, menstruation, and pregnancy. Lukacs and Largaespada (2006) stress the role that pregnancy plays in caries development. People have known that pregnancy has a negative impact on teeth for a long time, thus the phrase "for every child a tooth is lost" (Lukacs and Largaespada, 2006). Researchers in the 1930s and 1940s found that vital minerals, such as calcium, were lost by the expecting mother, making her teeth weaker and more susceptible to decay. With closer spaced pregnancies the mother is unable to fully recover the minerals and the effect increases with each subsequent child (Lukacs and Largaespada, 2006).

Pregnancy may contribute to caries incidences in other ways. With the added hormones and stress of pregnancy women often neglect oral hygiene, have a suppressed immune system, vomit, and/or experience odd food cravings that may result in higher carbohydrate intake (Lukacs and Largaespada, 2006; Ferraro and Vieira, 2010).

In contrast, Temple (2011) found that reproduction did not play a major role in caries pervasiveness. The number of carious lesions among the Jōmon era females of Japan showed no significant differences between age groups indicating that females who had never been pregnant and those with children had no variation in caries frequencies. This means that estrogen levels and probable fluctuating salivary rates did not play a role in cariogenesis for the Jōmon Period females (Temple, 2011).

Though females still had a higher number of caries than males in pre-agricultural populations, this bias became more evident with the advent of agriculture (Larsen, 1983; Lukacs, 1996; Fields et al, 2009). Lukacs (2008) argues that because of the negative effect of female reproductive biology on oral health and because of a boost in fertility rates with the advent of agriculture, the increase of caries in females is associated to the increase in reproductive activity. Lukacs (1996) acknowledges that food consistency and preparation methods as well as gender-based division of labor could explain some of the accentuated differences in caries frequencies.

Clearly there are many possible contributing factors to account for the higher rates of caries in females; nevertheless, previous studies have made several key pieces of information apparent. First, despite the fact that there are a few exceptions, females from all over the world are more often affected than their male counterparts. This bias is not an isolated occurrence but has been observed on all inhabited continents (Larsen, 1983; Walker and Erlandson, 1986; Lukacs and Largaespada, 2006). Secondly, females begin to develop more caries around the age of 12 and older (Jose and Joseph, 2003; Saravanan et al., 2003). Generally, 12 years is the age associated with puberty and may involve many biological and cultural changes that could have an impact on oral health. Finally, agriculture caused a dramatic increase in the number of caries in both sexes from most world populations and females are dramatically more affected (Larsen, 1983; Lukacs, 1996, 2008; Fields et al, 2009).

Many analyses regarding sex differences in dental health are flawed because they do not incorporate actual observations of dietary differences. Authors often rely on trends in human behavior rather than actual observations in the different cultures under consideration. For instance, Larsen (1997) states that field observations show there is a difference in food consumed by male and female foragers but not in male and female farmers. If true, then dietary differences do not explain the dissimilarity in caries frequencies between males and females.

All over the world and as far back as the Early Holocene, females have had a higher instance of caries than males (Larsen, 1983; Walker and Erlandson, 1986; Lukacs and Largaespada, 2006; Temple, 2011). Proposed explanations for this trend include diet, bacteria amounts, earlier female dental maturity, saliva, and hormones. Evidence indicates that there is probably not one cause but rather increased caries are a result of some combination of these factors.

2.8 Dental pathology studies focusing on sub-Saharan Africa

Compared to many parts of the world, Africa's sub-continent has been the subject of relatively few dental anthropology studies. This lack of research is surprising considering sub-Saharan Africa's sheer size and large population. Research that focuses on dental caries of anatomically modern humans from various parts of sub-Saharan Africa is missing from the literature. The few analyses concerned with dental pathology research of humans from Africa's sub-continent can be divided into three categories: conditional, descriptive, and comparative.

The conditional category refers to studies that have been conducted on contemporary populations in order to gain insights into a region's or certain demographic's health status. This is by far the largest category of the three, but also the least relevant to the current study. Most of the research aims at describing the health of children and how environment and diet affects dental health (Frencken et al., 1986; Solanki et al., 1991; Mackeown et al., 1995; Cleaton-Jones et al., 2000). Cleaton-Jones et al.'s (1999) meta-analysis of the trend in dental caries for Africa found a total of 69 relevant papers in an on-line search for the years 1967-1997. Even though the analysis included all of Africa, the 69 conditional-based research papers in a 30-year period is significantly more research than any of the other two categories.

Site reports with skeletal analyses for individuals or groups make up the descriptive category. In most bioarchaeological work a brief description of the dentition and dental pathologies is usually included (Flower, 1889; Morris et al., 1987; Steyn et al., 1998; Ohinata and Steyn, 2001; Pistorius, 2002; Steyn, 2003; Nienaber and Steyn, 2005; L'Abbe et al., 2008). These papers do not compare the number of caries to other individuals but usually use the dental pathologies to make some conclusion about the diet (i.e. high in carbohydrates). Including data from other sites would make the current study more complete but the lack of standardization in recording dental caries has led to their exclusion from the current study.

The comparative group is the least abundant but most relevant category to the present study. Comparative research relates the number of caries within a population or between two or more populations. One of the first comparative studies completed for sub-Saharan Africa was accomplished by Shaw (1931) with his work on the Bantu and their dentition. Shaw examined 132 skulls and found that 2.3% of all the teeth were carious. He also compared the instance for dental decay between each tooth and found that the first and second molars were most at risk for carious lesions in his Bantu sample. Furthermore, Shaw was able to include living people in his research by visiting a dentist office. His living population was made up of 151 males and 97 females where 6.5% and 7.8% of the total males' and females' teeth had carious lesions. Shaw's observations are useful, however his results are skewed by the fact that he visited a dentist office to get his data. He mentions that the patients at the dentist complained of a toothache and that all of them came to the dentist only because of dental problems.

Shaw came to three conclusions. First, even though a high number of Bantu dentitions were affected by caries, relatively few teeth were affected. Second, the Bantu have fewer caries than “modern civilized races” but more than “uncivilized races.” Lastly, the percentage of Bantu teeth affected by dental decay is more similar with that of “uncivilized races.” Lacking from Shaw’s research is a comparison between males and females and also through time. Even though he has the data, Shaw did not directly compare or try to explain the differences between the sexes. Similarly, Shaw could have compared his living sample to the deceased sample, although this could be somewhat problematic in that he did not know the age of the deceased.

A more thorough study was completed by Walker and Hewlett (1990). Their study focused on diet and social status of over 200 modern pygmy (Mbuti, Efe, and Aka) and Bantu individuals from central Africa. Results show that pygmy females have a higher rate of caries than pygmy males, but the difference between Bantu females and males is not statistically significant. High-status pygmies have a lower instance of decay at 12.5% compared to lower-status pygmies at 31.9%. Pygmies have a lower number of carious lesions than their agricultural Bantu neighbors because they eat less cariogenic food and more meat.

Sealy et al. (1992) applied lessons learned from studying living populations to LSA remains from South Africa. Over 60 skeletons from three different areas of Cape Province, South Africa, were examined for caries. Stable carbon isotope measurements along with the caries information determined the importance of marine foods in the diet and the abundance or lack of fluoride intake. Of the three samples, those taken from the coast show the lowest frequencies of caries with 2.5% of the total number of teeth showing lesions for females and 1.3% for males.

The non-coastal inhabitants recovered from Faraoskop, who consumed a mixed diet of marine and terrestrial foods, had a higher rate of caries at 8.7% for both sexes. Individuals from Oakhurst had a very high percentage of caries at 17.7% for both sexes, which the authors attribute to a lack of fluoride in the drinking water in the area. Sealy et al.'s (1992) research shows the possibility for marine dependent societies to be at less risk to dental decay than those who have a purely terrestrial diet. They also prove how great an impact on dental health fluoride can have, especially among prehistoric populations.

The research discussed above illustrates two important points. First, comprehensive dental studies focusing on comparing dental decay between populations and through time for sub-Saharan Africa are lacking. Reasons for this vary from political issues to a shortage of interest. Second, dental pathology studies are crucial for piecing together the lifestyles of past populations. The priority of the current study is filling in the gaps in the literature by providing a comprehensive study that covers time, space, cultural, and sex differences.

2.9 Conclusion

Overall, the study of the human dentition is vital for understanding past diets and lifestyles. Various factors such as diet, saliva, fluoride intake, attrition, and genetics can often make understanding caries development difficult and confusing but can also provide valuable information in deciphering global trends in caries rates. If anything, the above discussion emphasizes the need to examine the diet and lifestyle for each sample.

CHAPTER 3: REGIONAL BACKGROUND AND DESCRIPTION OF SAMPLES

Understanding how populations have changed through time, how the environment shaped human populations, and the antiquity of subsistence strategies are crucial for examining caries prevalence. Because a number of different factors affect dental health a summary of major cultural developments are provided below for three time periods: the Late Stone Age, Iron Age (Bantu Expansion), and Recent (Post-European contact). Following a general overview for each time period, specifics about each sample from the corresponding time period are discussed.

The dental samples for this project were recovered from various locations throughout sub-Saharan Africa and are now stored in several museums (Irish, 1993). The individuals are grouped by tribal/ethnic affiliation, linguistic classification, or by specific location of recovery (Irish, 1997). After a brief description of each time period, all of the samples are discussed with regard to the ecosystem the individuals lived in, diet, a brief cultural description, and any other relevant information. Table 1 provides a summary for each sample. Table 2 shows the total number of individuals, the number of males and females, and the number of individuals of undetermined sex.

3.1 Late Stone Age

3.1.1 Overview

Continuously oscillating climates, from arid to wet conditions, brought about major alterations to Africa's ecosystems around 14,000 years ago (Grove, 1995; Ehret, 2002). The northern-most regions of sub-Saharan Africa were the most affected as the Sahara wavered between habitable and uninhabitable conditions. During this time tropical rainforests and major lakes expanded and contracted (Marshall and Hildebrand, 2002; Clark et al., 2008). Fluctuating ecosystems brought about major changes to sub-Saharan Africa in the form of new technologies, distinctive cultures, and changing subsistence patterns. The Late Stone Age (LSA) technologies, also referred to as mode-4 and/or mode-5 technology, reflect how people altered their lifestyles to cope and, in some instances, thrive in their dynamic world (Clark, 1969; Phillipson, 2005).

The advent of LSA technologies were not always contemporaneous with one another, but rather developed at different times in separate parts of the sub-continent (Marshall and Hildebrand, 2002; Phillipson, 2005). Despite the independent onset of the LSA, technologies between different cultures looked surprisingly similar with only some regional specializations (Mercader and Brooks, 2001). Overall, the LSA is marked by a significant reduction in tool size and the presence of composite tools, backed lithics (blunting retouch), bows and arrows, and cultivation tools (Clark, 1962; Kusimba, 1999; Ehret, 2002; Phillipson, 2005; Barham and Mitchell, 2008). The LSA is also identified by a culture's complexity. The number of cave paintings, items of personal adornment, and formal burials increased indicating social hierarchies and complex abstract thought (Klein, 1992; Deacon and Deacon, 1999; Mitchell, 2004).

Similarly, cultural complexity can be observed in LSA subsistence patterns. Very little is understood in terms of what plants and animals were pursued and consumed as a result of a lack in site preservation of organic remains; nevertheless some general observations can be made (Marshall and Hildebrand, 2002; Phillipson; 2005; Barham and Mitchell, 2008). The vast majority of the people continued to hunt, fish, and gather food during the LSA but some in western and central Africa began to practice wild cultivation (Barham and Mitchell, 2008; Clark, 1962; Phillipson, 2005). Increasing the production of wild plants, such as yams, was one of the first steps toward agriculture (Ambrose, 1998). Animal domestication also appears to have started around this time (~4000 BP) in the form of guinea fowl and smaller hoofed animals, such as goats in western and central Africa and cattle in eastern and southern Africa (Marshall and Hildebrand, 2002; Phillipson, 2005).

The antiquity of pastoralism in sub-Saharan Africa is especially interesting because it predates agriculture in most parts of the continent (MacDonald, 1996; Marshall and Hildebrand, 2002). Some of the earliest dates come from Niger (5700 BP), Kenya (4000 BP and 4860 BP), and Tanzania (4020 BP) (MacDonald, 1996; Ambrose, 1998; Marshall, 2000; Wright, 2003; Smith, 2005; Lane, 2013). Pastoralism was brought to southern Africa about 2000 years ago as a result of the Bantu Expansion (Ehret, 1967; Klein, 1986; Smith 2005; Sadr, 2013).

Pastoralism spread to sub-Saharan Africa as a result of increasingly arid conditions in the Sahel and the expanding Sahara desert. Expansion of domestic animals farther south was hampered by diseases such as trypanosomiasis (sleeping sickness), theileriosis, and Rift Valley Fever (Clutton-Brock 1995; Gifford-Gonzalez, 2000; Lamphear, 2000). Eventually, some of the animals developed immunity to the diseases and, combined with changing environments, pastoralists were able to lead their herds farther south (Gifford-Gonzalez, 2000).

Cattle were and continue to be the most prized and revered of the domestic animals by far. Cattle were originally domesticated to provide a reliable source of meat, but for many pastoral groups cattle came to be prized possessions (Marshall and Hildebrand, 2002). Wealth and prestige depended on how many cattle a man owned and for many groups they played a major role in ritual, economic, and social life. Due to their high value, cattle were rarely slain, but rather used for their milk and blood. They were only killed as sacrifices during rituals (Lamphear, 2000).

Overall, the LSA is marked by an increase in cultural complexity that can be seen through new technologies, social practices, and changing subsistence patterns. Though food production and animal domestication were not widely practiced, their introduction into sub-Saharan cultures started a change that transformed the people and the sub-continent forever.

3.1.2 East African Samples (KHE, LHK, NGO)

KHE (Early Holocene Kenya), LHK (Late Holocene Kenya), and NGO (Ngorongoro Crater) make up the LSA East African group (Figure 1). The skeletal remains were collected from various sites throughout Kenya and Tanzania that date between 10,000 BP to 1000 BP. Several different cultural industries are represented in the samples including Pastoral Neolithic, Eburran (Capsain), and Elmenteitan (Cole, 1954; Rightmire, 1978; Protsch, 1978; Phillipson, 2005).

The savanna and its rivers provided the people with fish (tilapia and Nile perch), game (antelope, pigs, migratory ungulates), and plant foods (Robertshaw, 1988; Marshall, 1990; Bower, 1991; Barham and Mitchell, 2008). Grave goods, such as grinding stones, in some of the LHK sites indicate that people were utilizing plants, but there is little direct evidence for cultivation (Robertshaw, 1988). By 3000 BP, the Eburran industry was among the first to show signs that pastoralism was spreading to the region (Marshall, 1990; Barham and Mitchell, 2008).

Pastoral Neolithic cultures varied considerably from one another and from modern pastoralists in terms of how they utilized their domestic animals (Bower, 1991; Phillipson, 2005). Early Pastoral Neolithic people practiced hunting more than herding but the number of livestock remains in sites gradually increased until domesticates far outnumbered wild game (Bower, 1991). Pastoralism also brought about milk consumption, an important component to most pastoralists' diet (Marshall, 1990; Tishkoff et al., 2007).

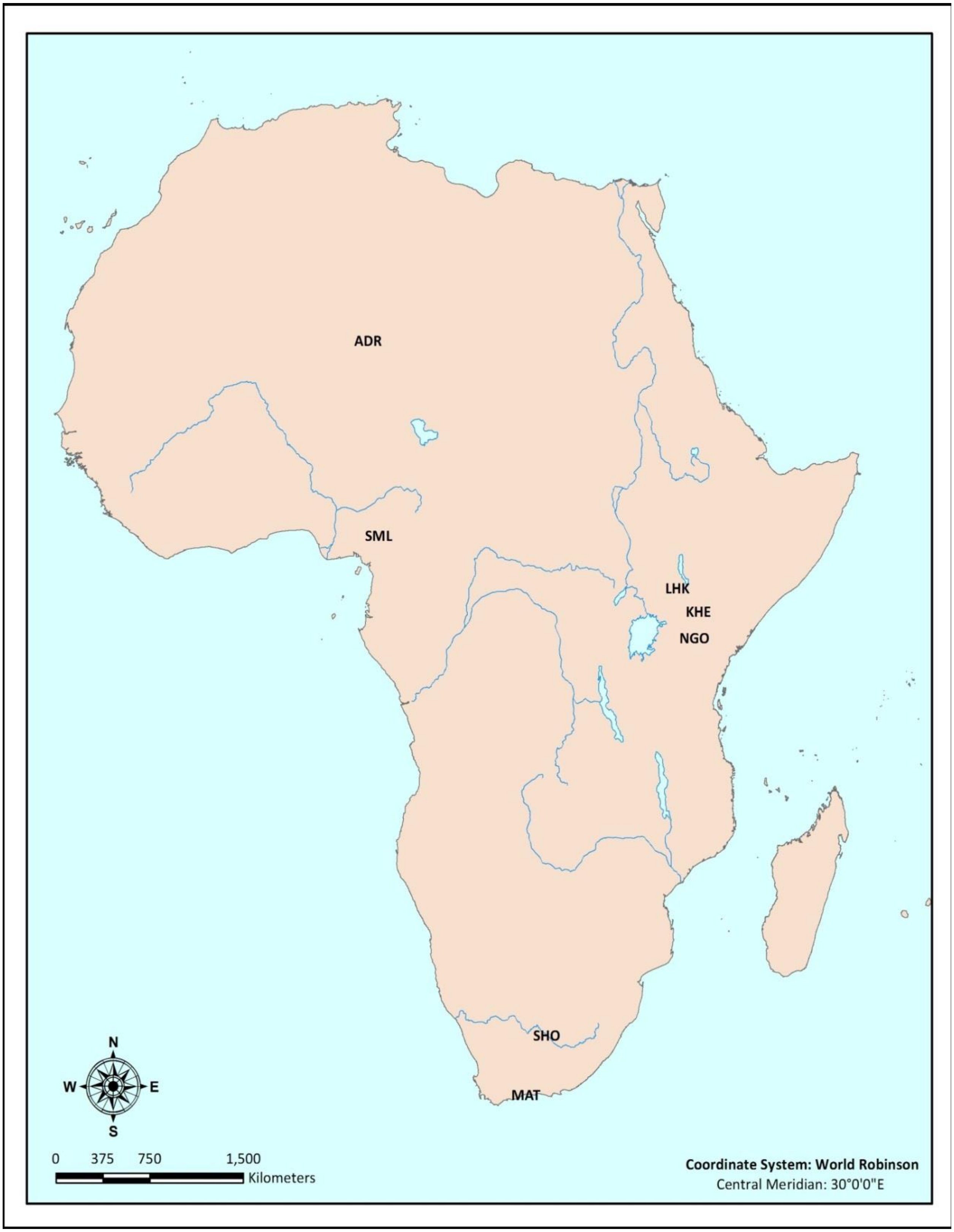

Figure 1. Map of Late Stone Age samples (modified from Irish, 1993, p. 179 with ArcGIS9, 2009)

3.1.3 West African Samples (ADR and SML)

The two groups comprising the West African sample come from the sites of Adrar Bous (ADR) in Niger and Shum Laka (SML) in Cameroon (Figure 1). The Adrar Bous area at 4000 BP was much more humid than it is today. Even though the area was still desert, numerous rivers could be found (Williams, 1971; Haour, 2003). Skeletons from Adrar Bous were collected from the stratigraphic level representing the Tenerian culture. The Tenerian industry, which peaked around 4000 BP, includes macrolithic technology, awls, flaked and ground stone, ceramic, drills, scrapers, retouched blades, knives, ostrich eggshells, axes, and adzes (Clark, 1971; Clark et al., 2008, Gifford-Gonzalez, 2008). Clark et al. (2008) believe the people of Adrar Bous were cattle herders who heavily relied on hunting (gazelle, hartebeest, and addax). Whether or not the Tenerian people cultivated any plants or what wild plants they gathered is still a mystery. Pottery and grindstones found at the site show that plant foods, possibly grains, were important to the diet (Haour, 2003).

Shum Laka Rock Shelter is a unique site because it shows continuous occupation from the Pleistocene to the Holocene (Cornelissen, 1996). Charcoal and one identified animal bone place Shum Laka in a mixed forest and grassland environment (Cornelissen, 1996).

The human remains found at Shum Laka are very fragmentary, but observed dental pathologies show that the diet was comprised primarily of plants, which is consistent with most hunter-gatherers (Maret, 1996; Ribot et al., 2001). Little is known about the precise diet of the Shuma Laka's inhabitants, but some suspect that rudimentary yam cultivation started around 3000 BP (Lavachery, 1996; Ribot, et al., 2001; Barham and Mitchell, 2008). Ribot et al. (2001) believe that it is possible that the diet may have included domesticated animals, dairy products, and cultivated crops. Even if domesticates were kept, hunting was probably still widely used (Lavachery, 1996).

The LSA deposits from Shum Laka date from 9000-6000 BP and then transition from the LSA to the Stone to Metal Phase (SMP) at around 4000 BP (Lavachery, 1996). Burials were recovered from both LSA and SMP levels and are pooled together for the current study because they were not separated during the recording process.

3.1.4 South African Samples (MAT and SHO)

The SHO (South African Holocene) sample contains skeletal remains collected from various sites all over South Africa (Figure 1). Technologically the people used the Wilton (8000 BP) industry, which includes microlithic tools as well as bows, poisoned arrows, diggings sticks with weights, and grinding stones (Oliver and Fagan, 1975; Deacon and Deacon, 1999; Ehret, 2002; Phillipson, 2005).

Deacon (1993) compares the diets of LSA hunter-gatherers to modern South African hunter-gatherers where 80% of the diet is plant foods such as bulbs, tubers, and corms. Hunters probably focused on small terrestrial game that was commonly found on the savanna, such as impala, bushbuck duiker, fish, and birds (Oliver and Fagan, 1975; Barham and Mitchell, 2008).

Matjes River Cave (MAT) lies along South Africa's coast (Figure 1). The site was occupied from 9000-2000 BP and represents one of the largest collections of material for the LSA in South Africa (L'Abbe et al., 2008). Artifacts collected from the site indicate that both Wilton and Albany industries were present (L'Abbe et al., 2008). The burials contained goods such as ochre, ostrich egg-shell ornaments, beads, awls, paint palettes, and stone artifacts (Louw, 1960). Isotope studies and material remains show that inhabitants of the Matjes River Cave ate mostly terrestrial foods but also consumed a high amount of marine foods (Sealy and Pfeiffer, 2000; Sealy, 2006). Louw (1960) describes the diet as consisting of antelope, bulbs and roots, fish, berries, and honey; however, because of poor excavation techniques, a great deal of data concerning subsistence was lost (Rightmire, 1978).

3.2 Iron Age/Bantu Expansion

3.2.1 Overview

The term Bantu refers to a group of languages that belong to the Niger-Congo family (for a more information on the African language phyla refer to appendix B) (Greenberg, 1972). The name itself derives from the similarities in the word "people" used in languages throughout Africa (Bleek, 1862). Bantu-speaking populations cover about one-third of the African continent which spans from Nigeria to Somalia and as far south as the Cape (Murdock, 1959; Davidson, 1969; Afolayan, 2000; Pakendorf et al., 2011). Since the introduction of the Bantu concept by Bleek (1862), researchers have been intrigued and puzzled by the origins and dispersion of such a huge language group (Eggert, 2004).

The notion of the Bantu Expansion refers to the massive extension of Bantu speaking peoples that started thousands of years ago and continued until heavy European colonization (Murdock, 1959). At first the discussion was limited to linguistics; however, through the years additional disciplines contributed to a broader understanding of the Bantu Expansion, and thus helped solve the mystery of why and how the Bantu came to dominate sub-Saharan Africa. For more information of the methods used to reconstruct the Bantu Expansion refer to Appendix C.

Linguistic evidence generally supports a proto-Bantu origin in Cameroon dating around 5000 BP (Greenberg, 1972; Ehret, 1982; Afolayan, 2000). Based on etymological analyses, proto-Bantu society can be described as socially stratified large groups (Afolayan, 2000). Bantu-speaking people probably relied on yams, palms, gourds, and groundnuts but did not have large-scale agriculture (Ehret, 1982; Vansina, 1984). Vocabulary reconstruction indicates that proto-Bantu relied heavily on rivers for food and transportation (Guthrie, 1962). The lack of common metallurgic terms suggests that iron and other metals had not yet been in use, thus showing that the proto-Bantu were still using stone tools (Afolayan, 2000).

Linguists speculate that the several proto-Bantu groups migrated to the East and established themselves near the Zaire River (Ehret, 1982; Afolayan, 2000). Early Bantu languages diverged from one another as Bantu people began to spread. By 2000 BP, perhaps as early as 3000 BP, the initial phase of language deviation ended and the larger Western and Eastern Bantu groups began to split apart (Guthrie, 1962; Oliver, 1966; Ehret, 1982, 2001; Vansina, 1995).

Some Western Bantu moved south from the Congo Bantu cradle, whereas the Eastern Bantu spread southeast (Figure 2) (Afolayan, 2000). Today, the boundary between the two follows the edge of the equatorial rainforest and the Rift Valley (Phillipson, 2005). The similarities within the Eastern Bantu languages suggests they are more closely related to one another than to the Western Bantu, and that the Eastern Bantu expansion south was relatively quick (Afolayan, 2000).

Archaeological finds correspond with linguistic evidence (Posnansky, 1968; Soper, 1982; Afolayan, 2000; Phillipson, 2005). The Chifumbaze complex (or Early Iron Age) is generally associated with the first Bantu-speaking peoples (Ehret, 1982, 2002; Holden, 2002). Most of the archaeological finds from the Chifumbaze complex are focused on the Eastern Bantu groups due to the lack of archaeological work in the areas inhabited by the Western Bantu-speaking groups (Phillipson, 2005).

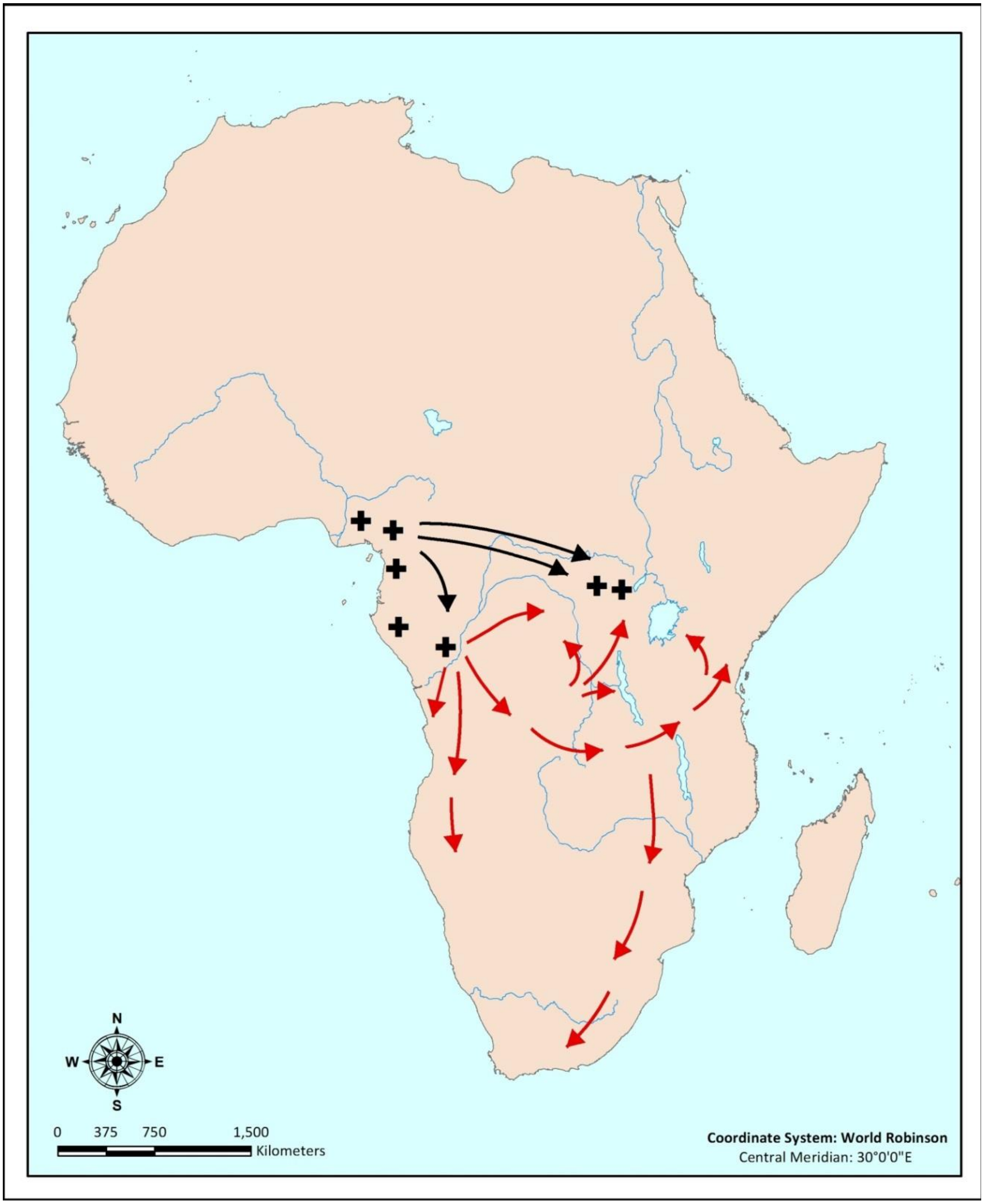

Figure 2: Map of Bantu language migration/diffusion. Black "+"s mark the original Bantu groups. The black arrows represent the Eastern Bantu movements and the red arrows represent the movement of Western Bantu (modified from Collins and Burns, 2007, p.49 with ArcGIS9, 2009).

The Chifumbaze complex is associated with Urewe and Kwale pottery types. Posnansky (1968) suggests that the producers of both the Urewe and Kwale wares started in western Africa then moved East during Bantu migrations. Dating techniques show a fairly rapid dispersal for both pottery types (Afolayan, 2000; Phillipson, 2005). Urewe pottery is distinguished by the presence of dimples on the base, beveled rims, and channel decorations (Afolayan, 2000). Urewe pottery spread to the eastern and southern regions of the sub-continent around 1900-1600 BP, probably through the use of river systems (Soper, 1982; Afolayan, 2000). In most instances iron is present in Urewe ware sites. Studies of this technology indicate a rapid movement to the South as a possible result of preferred environments (Afolayan, 2000).

Kwale pottery shows that other ecosystems were also used by the Bantu. Kwale ware has been found in northern Tanzania and central Kenya (Soper, 1982). This pottery type is found mostly in forest margins and mountain slopes (Afolayan, 2000). Kwale sites range in antiquity from 1800-1000 BP and are commonly associated with iron artifacts (Afolayan, 2000).

As Bantu-speaking peoples dispersed across sub-Saharan Africa so did their technologies and ways of life. The Bantu are credited with spreading metallurgy, agriculture, animal domestication, and sedentary life (Afolayan, 2000; Phillipson, 2005). The exact mode (migration, diffusion, etc.) for how the technologies expanded is still not fully understood and is discussed below.

Signs of metal use in the sub-continent began around 2800 BP, after the Bantu-speaking populations began to move (Afolayan, 2000; Phillipson, 2005). Afolayan (2000) states that metal was used for currency and jewelry, which were important items for trade, marriage, and political exchange. Metals, especially iron, copper, and gold, were slowly incorporated into the Bantu culture and were often used simultaneously with stone (Childs and Herbert, 2004).The origins and methods for metallurgy in early sub-Saharan Africa are still under debate mostly due to the fact there is little evidence in the archaeological record (Gailey, 1970; Childs and Herbert, 2004).

Metal use allowed more intensive agriculture. In the forest, vegetables and root crops were widely cultivated. Later, as the Bantu spread further South into the savanna, cereals became the crop of choice (Ehret, 1973; Phillipson, 2005). Linguistics also shows that cattle and sheep were introduced from non-Bantu sources, but goats were even used during the initial migration (Ehret, 1973; Phillipson, 2005).

Questions remain as to how the Bantu-speaking peoples spread across such a large area and what happened to the previous inhabitants once the Bantu arrived. Was there a large migration of people or rather a diffusion of language and technologies? Were the previous inhabitants forced out, killed by warfare, or did they assimilate and work alongside their new neighbors? Overall, there is not one answer, but several depending on the circumstances.

There is no support for a mass exodus of Bantu-speaking people. A more likely scenario is the spread of people for new lands to farm and natural drift (Afolayan, 2000; Pakendorf et al., 2011). Bantu dispersal was fairly slow and continuous (Ehret, 1982). The success of agriculture had a major influence on local populations. Bananas probably had the biggest impact because of their higher yields, resilience, and easy growing methods (Murdock, 1959). Afolayan (2000) argues that “Bananas produced a flurry of colonization and expansion as well as an economic and demographical revolution with far-reaching consequences” (p.128). Agricultural success led to an increase in population size and thus the need for further development and expansion.

Assimilation of already existing populations might have been a major factor. The incorporation of iron tools into the culture attracted followers from other groups. Weapons and agricultural tools likely increased the success of hunting, warfare, and crop yields (Childs and

Herbert, 2004). For these reasons iron was essential in understanding how assimilation of other populations into Bantu-speaking populations occurred (Afolayan, 2000).

Sheer numbers were a major contribution to local population assimilation. Larger Bantu populations provided a source of trade and new innovations for the smaller hunting groups. As the hunters became more dependent on Bantu goods, they were gradually absorbed into the larger group (Afolayan, 2000; Phillipson, 2005). Holden and Mace (2003) found that once a culture borrowed the practice of herding cattle, their matrilineal descent was replaced with the more Bantu-like patrilineal descent, thus showing how borrowed innovations can eventually lead to assimilation.

Distinct non-Bantu cultures that predate the Bantu Expansion still exist today. For the most part they belong to the Khoisan language group and include the San and Khoikhoi of South Africa as well as the pygmies of Central Africa (Afolayan, 2000). Even though these groups have not been fully integrated into the Bantu culture they still rely on the Bantu for trade and jobs (Afolayan, 2000). The existence of such groups confirms that not all the Bantu-speaking groups used warfare to wipe out the other populations. Smaller hunting groups provided valuable trade goods to the stationary and agriculturally dependent Bantu. For instance, wild game and gathered foods may have provided a much appreciated variation in the diet.

Whatever factors drove the Bantu Expansion, whether the physical migration of people or a diffusion and eventual assimilation of already existing cultures, there is no doubt that technology played a pivotal role. Overall, the Bantu Expansion shows that the people were very adaptive, influential, and innovative.

3.2.2 West African Samples (FVR)

Intensive archaeological work during the late 1990s has resulted in the discovery of Iron Age sites in Burkina Faso, especially in the Voltaic Rivers region. Excavations have yielded human remains, furnaces for iron working, and pottery (Dueppen, 2008). Holl and Kote (2000) refer to the culture as belonging to the Mound Complex, which dates from around 2700-600 BP.

The people of the Voltaic Rivers region in Burkina Fosa (Figure 3) were using iron by 2300 BP but iron-working was not widely used in the area until around 1500 BP (Oliver and Fagan, 1975; Phillipson, 2005). During the Iron Age people in the region relied on plant domesticates such as millet, sorghum, and yams for food (Oliver and Fagan, 1975; D'Andrea and Casey, 2002; Phillipson, 2005). Cattle were also important to the economy but probably were not regularly slaughtered for food (Phillipson, 2005). Instead, sheep, goats, and chickens were kept as reliable sources of protein (Dueppen, 2008). Faunal evidence suggests that the savanna environment provided a large variety of wild game including antelope, duiker, bushbuck, hartebeest, and warthogs for hunting (Dueppen, 2008).

3.2.3 Central African Samples (DBI and UPB)

The Iron Age in central Africa dates to 2500 BP (Ehret, 2002; Phillipson, 2005). Both the DBI (Democratic Republic of the Congo Iron Age) and UPB (Upemba Valley) samples are from the Democratic Republic of the Congo (Figure 3) and include sites such as Sanga, Kamilamba, and Kikulu. Inferences about early diets have to be made by looking at ceramics and other tools used to collect crops because organic remains in central Africa are sparse (Denbow, 1990). Material remains show intensive use of oil palms while linguistics suggests that other crops, such as yams, ground beans, and bananas were being exploited (Ehret, 1982; Vansina, 1984; Denbow, 1990). After 1700 BP other crops were introduced, such as bananas, sugar cane,

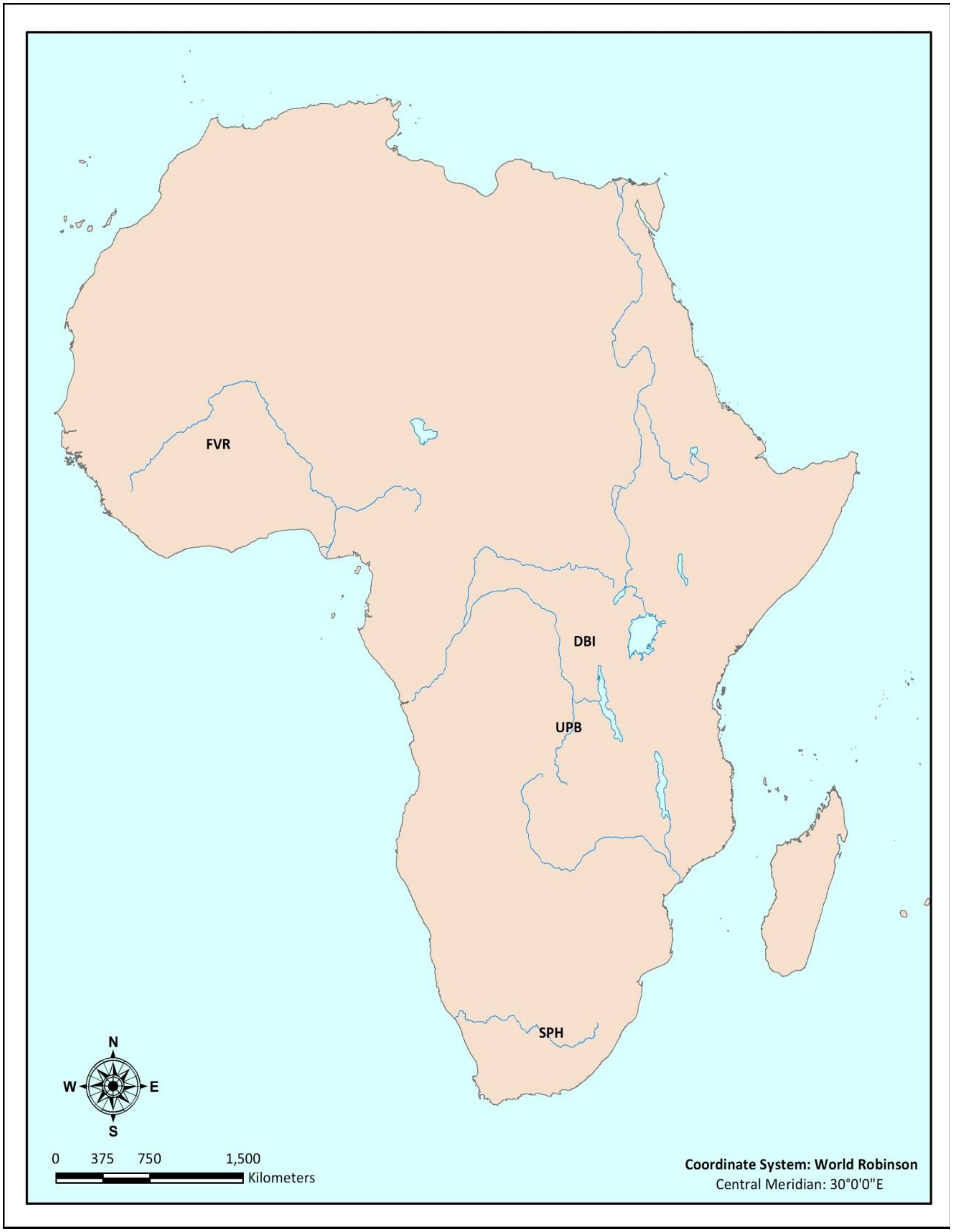

Figure 3: Map of Iron Age samples (modified from Irish, 1993, p. 179 with ArcGIS9, 2009)

citrus fruits, and Asian rice (Davidson, 1969; Ehret, 2002). Trade played a very important role in the early distribution of iron. Only a few localized areas had access to iron ore so many other communities specialized in fishing, copper, or salt (Oliver and Fagan, 1975; Ehret, 2002).

Extensive trade attracted people from all over the area to converge and develop into a complex society called Kisalian (Maret, 1979; Ehret, 2002). The Classical Kisalian is marked by a major leap in political organization in which people paid taxes in order to use the resources of the land. At the site of Sanga, royalty were buried with a rich array of grave goods, including iron hoes, knives, axes, spears, arrows, harpoon heads, fish hooks, necklaces, and elaborate pendants (Oliver and Fagan; 1975; Maret, 1979; Ehret, 2002).

Fishing and agriculture were the main sources of food for the Kislain people (Maret, 1979). They also people had some domesticates in the form of goats and chickens (Maret, 1979). The forests and savanna also provided for the hunting of antelope, hippopotamuses, and crocodiles (Maret, 1979; Ehret, 2002).

3.2.4 South African Samples (SPH)

The SPH (early historic South Africa) sample (Figure 3) encompasses a heterogeneous array of indigenous South African people, Khoisan, from the early historic period. The Khoisan of South Africa did not widely use iron until relatively recently and even then it was only obtained through trade with the Bantu. For the most part the Khoisan continued their lives as hunter-gatherers or nomadic pastoralists (Ehret, 2002). Both cattle and pottery spread to the region around 2000 years ago (Hausman, 1984; Sadr, 1998). In the eastern parts of southern Africa some Bantu-speaking communities practiced agriculture and often traded with the Khoisan people for fresh meat or livestock products (Deacon and Deacon, 1999; Afolayan, 2000; Ehret, 2002). At around 2000 BP the Khoisan divided into two groups: the Khoikhoi, who were pastoralists; and the San, who remained hunter-gatherers (Deacon and Deacon, 1999; Ehret, 2002; Collins and Burns, 2007). By the time Europeans arrived at the Cape in the 17th century the two groups could be distinguished from one another based on physical appearance, with the Khoikhoi usually being taller than their San counterparts (Hiernaux, 1975; Collins and Burns, 2007).

Until the arrival of the Europeans, the Khoisan remained fairly isolated (Hausman, 1984). The Bantu did not occupy much of southern Africa because the desert environment could not support their agricultural way of life. Khoikhoi were able to persist as pastoralists only because they supplemented much of their diet with gathering and were able to migrate without fear of competition (Elphick, 1977; Phillipson, 1977).

3.3 Post-European contact

3.3.1 Overview

The arrival of Europeans in South Africa (16th century) and the increase in the number of traders in eastern Africa marked the beginning of a new era for sub-Saharan Africans. Europeans forced Africans into labor locally and abroad, they took most of the productive land, and caused massive migrations of people (European and African) (Reader, 1997; Moradi, 2009). Traders from Asia and the Americas introduced new crops, transforming the economy (Tosh, 1980). As a result of the massive changes, lifestyles, including diet and health, were greatly altered.

Portugal was among the first of the European countries to have a significant impact on sub-Saharan Africa. Under the direction of Prince Henry the Navigator, Portugal was able to make their ships worthy for long explorations. Once discovered, Africa's West coast provided Portugal with slaves, spices, and gold, all of which helped fund further probes along Africa's coast. In 1497 Vasco da Gama sailed to Africa's East coast, effectively securing Portugal's trading network with the East. However, Portugal's hold on West Africa was weak due to an increase in the slave trade and politically unstable locals. Even with Portugal's weak presence, Europeans continued to have a strong influence on the Gold Coast well into the 20th century because of the extensive and lucrative slave trade (July, 1998).

European and native African relations were just as violent in southern Africa. The first European settlers colonized the Cape of Good Hope in South Africa. The Dutch believed the region had a Mediterranean-like climate and lacked inhabitants (Reader, 1997). However, life in the new settlements did not turn out as pleasant as originally planned. The Khoisan rebelled in 1659 after discovering that the Dutch were now permanent settlers on their land. After a severe epidemic in 1713 the Khoisan were compelled into joining the Dutch labor force. In 1779 a series of wars broke out between the Dutch Boers and the native Xhosa over productive land. Once the British took over the colony in 1806 they defeated and pushed out the Xhosa. Soon after, the expansion of the British colony and war path of the Zulu, another local people, caused widespread population dispersal as people were forced to find new homes (Reader, 1997; July, 1998).

Central Africans also became victims of ambitious Europeans. Belgium's notorious King Leopold played a particularly nasty role in the history of the Congo basin once he obtained control of the region in 1885 through the Berlin Conference. As a result of strict European demands all the efforts of the locals went into harvesting rubber and none into growing food. The population prior to the Congo concession was 20 million, by 1911 only 8.5 million were left (Reader, 1997). The Berlin Conference of 1884-1885, which divided up the sub-continent between various European countries. England, France, Portugal, Germany, Belgium, and Italy all claimed regions of Africa, often regardless of preexisting boundaries (Barnett, 2000; Collins and

Burns, 2007). Each country had their own method for ruling over their allocated regions, but each had the goal to make the colonies self-sufficient financially and profitable to their metropolitan state (Collins and Burns, 2007).

The cash-crop economy of the late 19th century replaced traditional nutrient rich foods (Raschke and Cheema, 2007). Africans were coerced into modifying their gardens and crops to include cloves and rubber trees in order to pay for the taxes imposed on them (Barnett, 2000; Raschke and Cheema, 2007). Even the Africans who were not agriculturalists were affected since considerable amounts of land were cleared, thus eliminating many of the indigenous foods (Raschke and Cheema, 2007). Many Africans were confronted with the choice to work on European-owned land or be pushed to land that could not support agriculture or livestock (Raschke and Cheema, 2007; Moradi, 2009).

The stress and dietary change took a negative toll on African health (Steyn, 2003; Raschke and Cheema, 2007; Moradi, 2009). Life expectancy at birth declined during post-colonial times (Steyn, 2003). Nutrient deficiencies were common due to the reduction of varying foods in the African diet and increase in reliance on low-quality foods such as wheat, rice, and maize (Raschke and Cheema 2007).

3.3.2 East African Samples (ETH, HAY, KEN, KKU, NLT, SOM, TAN, and TEI)

Modern eastern Africa (Figure 4) encompasses grasslands and savanna that are used for grain crops and cattle herding (Kitalyi and Kabatange, 1988). In areas where herding is popular, cattle provide not only food, but bring their owners prestige and power. The cattle’s milk is consumed in various ways, especially in the form of porridge and mixed with grains. Fishing is also popular in areas close to lakes (Ottenberg and Ottenberg, 1960; Taylor, 1970).

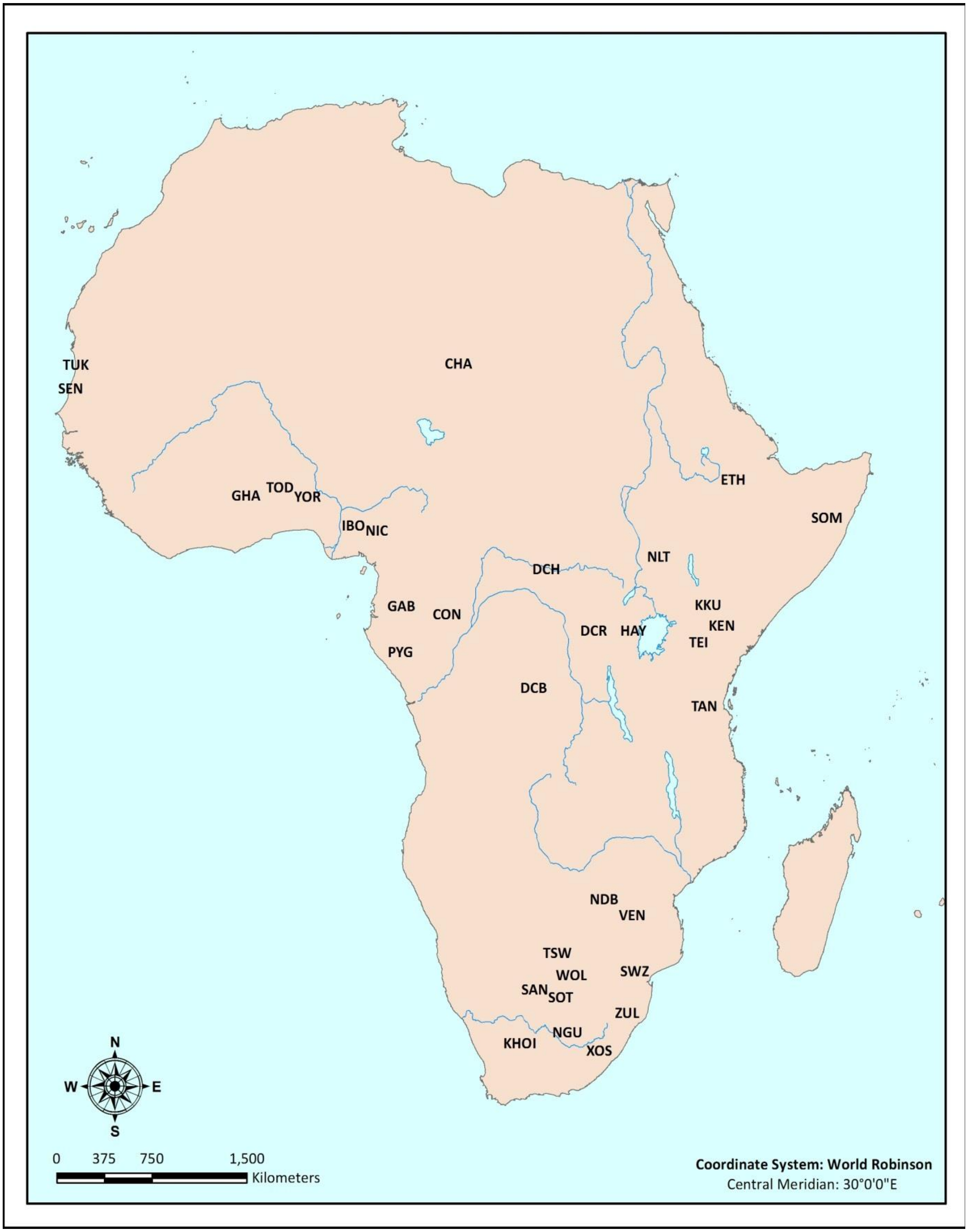

Figure 4: Map of Recent samples (modified from Irish, 1993, p. 179 with ArcGIS9, 2009)

The individuals that make up the KEN (Kenya), KKU (Kikuyu), and TAN (Tanzania) samples rely on a mixed economy of agriculture and pastoralism (agro-pastoralists). Women are often in charge of the horticulture and food processing while men are responsible for the goats, sheep, and a small number of cattle (Newman, 1970; Clark, 1980). Some crops, such as sweet potatoes, sugar cane, and bananas are often cared for by men, but women take care of the staple crops such as maize, beans, and millet (Clark, 1980; Taylor, 1970; Funder et al., 2013). Other commonly grown crops include sorghum, cowpeas, and various pumpkins and melons (Newman, 1970). Economically, these East African populations rely primarily on agriculture to fulfil their dietary needs. Herding, especially of sheep and goats, has become more common over time (Taylor, 1970).

The Taita (TEI) are agriculturalists who also keep small herds of cattle and goats. Their staple foods include maize, sugar cane, beans, rice, potatoes, sweet potatoes, yams, taro, bananas, and cassava (French-Sheldon, 1892; Hambly, 1940; Fleuret and Fleuret, 1991). Taita women are renowned for their elaborately ornamented dress in the form of beaded collars, which forces the chin up, and their beaded aprons (Johnston, 1886; Hambly, 1940).

The Haya (HAY) are predominantly agriculturalists. Their mainstay is bananas but coffee, maize, millet, sorghum, beans, cassava, and sweet potatoes are also grown. Bananas only became popular for the Haya once they incorporated cattle into their farms. The manure is used to provide the extra nutrients needed for the plant to grow successfully (Maruo, 2002).

Nilotes (NLT) are a highly nomadic people who depend on cattle for subsistence, wealth, and religion. Generally, pastoralists are limited to living on the plains where the land is unsuitable for large scale agriculture. Cattle are rarely slaughtered for their meat, but rather provide their keepers with milk and blood. Nilotes rely on nearby agriculturalists for grains and other plant foods. This relationship between pastoralists and farmers can take many different shapes; some extend dominion over their neighbors, while others trade protection for food. Pastoralists remain nomadic so they can travel to areas where the vegetation is most prolific and to provide their cattle with different sources of grasses, which provide a variety of necessary nutrients and minerals (Schneider, 1957; Lamphear, 2000).

The SOM (Somalia) sample is a mix of pastoralists and agriculturalists. The Digil and Rahanweyn rely on growing crops such as bananas in the fertile riverine areas (Konczacki, 1967; Farah and Lewis, 1997). The vast majority of the people in the semi-desert zones are predominantly pastoralists. Both cattle and camels are collected to increase an individual's prestige and an animal's byproducts are consumed. As with the Nilotes, the people comprising the SOM sample are nomads; they are always moving in search of water and better grazing lands (Konczacki, 1967).

Geographic isolation from the rest of sub-Saharan Africa and a varied array of environments has allowed the individuals of the ETH (Ethiopia) sample to develop a unique subsistence base (Phillipson, 1995; Adejumboi, 2001). Most notable is the cultivation of teff, a locally domesticated cereal used to make bread. Other significant crops include wheat, barley, millet, ensete, ch'at, coffee, and noog. Keeping cattle is not as popular in Ethiopia as in other parts of sub-Saharan Africa, but sheep and goats are more common. Plant domestication and cultivation has ancient origins in Ethiopia. Until recent times very little has changed in how the people cultivated their crops; many people still use the ancient ox-drawn plow method for planting (Brandt, 1984; Phillipson, 1995).

3.3.3 Central African Samples (CHA, CON, DCB, DCH, DCR, GAB, and PYG)

Central Africa can be divided into two large ecosystems: savanna and forest. The populations residing in these ecosystems rely on agriculture, but the crops vary between the two. Both the CON (Congo) and CHA (Chad) samples are comprised of individuals from the savanna regions of central Africa. The CON includes people from the Zanaga District of the Republic of the Congo. Major crops included grains such as maize but cassava, groundnuts, voandzea, and bananas were also grown. Large livestock are rare but smaller domesticates, such as dogs, chickens and goats are common. In addition to growing crops, the people collect wild plants, fish, and hunt animals such as buffalo, elephant, monkeys, weaverbirds, and antelopes (Forde and Jones, 1950; Laman, 1953; Vansina, 1973).

Similar to the CON individuals the CHA sample includes agriculturalists as well as pastoralism and fishing. The Toubou, Masalit, and Kanembu practice a mix economy of raising and herding camels and cattle but also spear fish, collect and eat algae (*dihé),* and grow small crops (Ottenberg and Ottenberg, 1960; Batello et al., 2004).

Samples DCH (northern central Democratic Republic of the Congo), DCB (southern half of the Democratic Republic of the Congo), DCR (eastern Democratic Republic of the Congo and Rwanda), and GAB (Gabon) are composed of forest dwellers who rely upon an entirely different set of crops. Sections of forests are often cleared for root crops such as yam, taro, bananas, palm fruits, plantains, and other fruits (Forde and Jones, 1950; Ottenberg and Ottenberg, 1960). By the 1600s, central Africa was undergoing a crop revolution which started when new plants were introduced from Central and South America. Farmers introduced maize, cassava, sweet potatoes, and fruits such as pineapple and pawpaw into their crop cycle (Davidson, 1969). Large cattle and other domesticates are rare due to the tsetse fly; however goats, sheep, chickens and ducks are often kept (Forde and Jones, 1950; Ottenberg and Ottenberg, 1960; Gardinier, 1981).

Pygmies (PYG) are among the last of the hunter/gatherers in central Africa. Pygmy diets are varied and will often consist of fish, swine, monkeys, caterpillars, maggots, snakes, ants, mice, other big game, bananas, plantains, mushrooms, and an assortment of berries and nuts (Dowd, 1969; Walker and Hewlett, 1990). Nomadic Pygmy bands often settle near Bantu agricultural villages to trade game, honey, and other forest products for farm-grown food and iron tools (Ottenberg and Ottenberg, 1960)

3.3.4 West African Samples (GHA, IBO, NIC, SEN, TOD, TUK and YOR)

As with the central African samples, the West African (Figure 4) samples can be divided into two broad geographical categories, those from the savanna and those from the forest. Like most people who live on the savanna, individuals making up the SEN (Senegambia) and TUK (Tukulor) samples focus on grain crops such as millet, fonio, and sorghum for their daily food. Other crops include cowpeas, beans, peanuts, and some rice. Techniques for harvesting the crops varies greatly, but for those who are able to produce a surplus grow additional cash crops such as cotton. Livestock in the form of cattle and camels are also common. Some agricultural groups have a symbiotic relationship with nearby pastoralists where plant foods are traded for livestock byproducts (Forde and Jones, 1950; Skinner, 1973; Tymowski, 1991; Faye, 2013).

GHA (Ghana), IBO (Ibo), NIC (Nigeria and Cameroon), TOD (Togo and Dahomey), and YOR (Yoruba) samples are comprised of people who live in the forest. Forest inhabitants rely on root crops such as yams, taro, and cocoyams. Other crops such as rice, okra, peas, gourds, pumpkins, beans, and bananas are also frequently grown. The tsetse fly has prevented large scale herding in the forest regions, but some animals such as dwarf cattle, goats, sheep, chickens, ducks, bees, and guinea fowl are fairly common (Bascom, 1951; Busia, 1954; Forde and Jones, 1950; Skinner, 1973; Verdon, 1983). Many of the populations, such as the Ashanti (GHA), Ewe (TOD), Fon (TOD), have had great economic success in that there is much occupational specialization and often permanent standing armies (Manoukian, 1952; Mercier, 1954; Afolayan, 2000).

3.3.5 South African Samples (KHOI, NDB, NGU, SAN, SOT, SWZ, TSW, VEN, WOL, XOS, and ZUL)

The southern African samples (Figure 4) can be divided into two broad categories: Bantu and Khoisan. The Bantu groups keep to the savanna and grasslands where the earth is more fertile and there are plenty of resources for livestock. The Khoisan often reside in the desert where they remained unbothered by the expanding Bantu populations, at least until Europeans arrived.

The Bantu practice pastoralism, agriculture, and sometimes a mix of the two. The SOT (Sotho), SWZ (Swazi), and WOL (Wolmaransstad) samples are made up of individuals who practiced agriculture. Crops such as maize, millet, sorghum, pumpkins and groundnuts are often grown. In most cases a few cattle are kept but are used for wealth other than food (Krige and Krige, 1954; Maylam, 1986; Zeleza, 1997).

Pastoral groups, such as those belonging to the NDB (Ndebele), XOS (Xosa), and ZUL (Zulu) samples, rely on cattle for wealth and food (Lye, 1969; Chanaiwa, 1980; Webster, 1986; Gump, 1988). As with most pastoral groups the cattle are rarely killed for food but rather are only killed and eaten during ceremonies. Other livestock are often kept only for slaughter such as sheep and goats. Some small-scale agriculture is practiced by growing grain crops such as maize and millet (Schneider, 1957; Ballard, 1981; Reader, 1997, Elmslie, 2013).

The Agro-pastoralists included in the NGU (Nguni), TSW (Tswana), and VEN (Venda) samples depend on an equal mix of crops and cattle for their economy. Basic crops include sorghum and maize, although watermelons, gourds, beans, pumpkins, potatoes, bananas, and tobacco are also grown. Like the other pastoralists in the region, cattle are rarely killed for consumption but their byproducts such as milk are a chief ingredient in the diet (Ballard, 1981; Maylam, 1986; Zeleza, 1997; Elmslie, 2013).

The Khoikhoi (KHOI) and San (SAN) make up the second broad South African group. Both the Khoikhoi and San have very ancient origins and were once more widespread throughout Africa. The Khoikhoi are a pastoral people who keep cattle, sheep, and goats. Only the cattle that die of old age, disease, or for ceremonial reasons are eaten. Milk and butter make a large portion of the Khoikhoi diet but hunting also provides meat (Boonzaier et al., 1996).

The San live mainly in the Kalahari Desert and survive by hunting and gathering. Each family is self-sufficient. San men hunt wild game such as antelopes and ostriches, while San women are responsible for collecting plant foods such as roots, bulbs, berries, tubers, figs, palms, and nuts as well as small slow game. San groups remain small due to limited and scarce amounts of water and food (Dowd, 1969; Ottenberg and Ottenberg, 1960; Marshall, 1973).

3.4 Conclusion

Sub-Saharan Africa has witnessed major cultural changes in the past 10,000 years as a result of changing environments, migration, and European contact. These cultural changes affected people's diets and, subsequently, their dental health. Also, the diversity of the populations' lifestyles, including their subsistence strategy and where they live, will influence a group's diet and, thus differences in caries counts should be observed.

Table 1. Summary of samples

Code	Full Name	Culture	Ecosystem	Time period	Economy/diet	Main economy	References
ADR	Adrar Bous	Tenerian	Desert	9600-3000BP	Pastoralist: cattle	Pastoralism	Browthwell and Shaw, 1971; Clark, 1971; Clark et al, 2008
CHA	Chad	Toubou, Masalit, Kanembu	Savanna	19th-20th century	Agriculturalist: grains; Pastoralist: cattle and camels	Agriculture	Ottenberg and Ottenberg, 1960; Batello et al., 2004
CON	Congo	Teke(Tio), Kongo	Savanna	19th century	Agriculturalist: maize, cassava, and bananas; fishing	Agriculture	Laman, 1953; Forde and Jones, 1950; Vansina, 1973
DBI	Democratic Republic of the Congo	Kisalian	Rainforest	Iron Age	Agriculturalist: yams	Agriculture	Oliver and Fagan, 1975
DCB	Southern Democratic Republic of the Congo		Rainforest	19th century	Agriculturalist: yams taro bananas and plantains; fishing	Agriculture	Forde and Jones, 1950; Davidson, 1969

Table 1. continued

DCH	North central Democratic Republic of the Congo	Bassoko and Azande	Rainforest	19th century	Agriculturalist: yams taro bananas and plantains; fishing	Agriculture	Forde and Jones, 1950; Davidson, 1969
DCR	Eastern Democratic Republic of Congo and Ruanda	Tutsu, Hutu, Twa	Rainforest	19th century	Agriculturalist: yams taro bananas and plantains; fishing	Agriculture	Forde and Jones, 1950; Davidson, 1969
ETH	Ethiopia	Heterogenous sample	Savanna	19th-20th century	Agriculturalist: bananas, several types of grains, teff	Agriculture	Brandt, 1984; Adejumboi, 2001
FVR	Voltaic Rivers	Kirikong, Voltaic	Savanna	Iron Age	Pastoralist: cattle; Agriculturalist: millet, cowpeas, and yams	Pastoralism	Holl and Kote, 2000; Dueppen, 2008
GAB	Gabon	Fang, Nkomi, Lumbo, Mpongwe, Bakale and Adouma	Rainforest	19th-20th century	Agriculturalist: yams taro bananas and plantains; fishing	Agriculture	Forde and Jones, 1950; Davidson, 1969
GHA	Ghana	Ashanti (Asanti) and Fanti	Rainforest	19th century	Agriculturalist: root plants, cola nuts	Agriculture	Manoukian 1952; Busia, 1954; Mercier, 1954

Table 1. continued

HAY	Haya	Haya	Savanna	19th century	Agriculturalist: bananas, maize, common bean, cassava, sweet potato Pastoralist: cattle	Agriculture	Maruo, 2002
IBO	Ibo	Ibo (Igbo)	Rainforest	19th century	Agriculturalist: root plants, cola nuts	Agriculture	Manoukian, 1952; Forde and Jones, 1950
KEN	Kenya	Kikuyu, Swahili, Lamo, Chaga, and Pare	Savanna	19th-20th century	Agriculturalist: millet, sweet potatoes, bananas, and beans; Pastoralist: primarily goats and sheep and some cows	Agriculture	Taylor, 1970
KHE	Early Holocene Kenya	Gambles Cave, Bromheads (Elmenteita), Lothagam, Naivasha, Kanam Shell Mound	Savanna	10,000-3500BP	Hunter gatherer: antelopes and pigs; fishing	Hunter/ gatherers	Protsch, 1978; Robertshaw, 1988, Barham and Mitchell, 2008

Table 1. continued

KHOI	Khoikhoi	Nama and Korana	Desert	19th century	Pastoralist: cattle and sheep	Pastoralism	Boonzaier et al., 1996
KKU	Kikuyu	Kikuyu	Savanna	19th century	Agriculturalist: millet, sweet potatoes, bananas, and beans; Pastoralist: primarily goats and sheep and some cows	Agriculture	Taylor, 1970; Clark, 1980
LHK	Late Holocene Kenya	Pastoral Neolithic: Nakuru, Willey's Kopje, Makalia, Njoro River Cave, Hyrax Hill etc.	Savanna	3000-1000BP	Hunter gatherer: antelopes and pigs; Pastoralist: cattle, sheep, and goats	Hunter/ gatherers	Cole, 1954; Sutton, 1998
MAT	Matjes River Cave	Wilton	Coastal	9000-2000BP	Hunter gatherer: fishing	Hunter/ gatherers	Rightmire, 1978
NDB	Ndebele	Ndebele	Savanna	20th century	Pastoralist: cattle	Pastoralism	Lye, 1969

Table 1. continued

NGO	Ngorongoro Crater	Late Stone Age	Savanna	700 BC	Hunter gatherer: antelopes and pigs; fishing	Hunter/ gatherers	Leakey, 1966
NGU	Nguni	Zulu, Xhosa (Xosa), Swaziland (Nguni)	Savanna	19th century	Pastoralist: cattle; Agriculturalist: maize, sorghum and sugarcane	Pastoralism	Maylam, 1986; Zeleza, 1997
NIC	Nigeria/ Cameroon	Efik, Ibibio, Boki and Anyang	Rainforest	19th century	Agriculturalist: root plants, cola nuts	Agriculture	Manoukian, 1952
NLT	Nilotic	Nilotic	Savanna	19th century	Pastoralist: cattle; some fishing and farming	Pastoralism	Schneider, 1957; Lampher, 2000
PYG	Pygmy	Binga and Bongo	Rainforest	19th-20th century	Hunter gatherer: fish, insects, berries and plantains	Hunter/ gatherers	Dowd, 1969; Walker and Hewlett, 1990
SAN	San	!Kung, Naron Tshakwe, Mkaukau, and Gwikwe	Desert	19th-20th century	Hunter gatherer: antelope, ostriches, roots, bulbs, tubers, figs, palm, and nuts	Hunter/ gatherers	Dowd, 1969; Marshall, 1973

Table 1. continued

SEN	Senegambia	Wolof, Balante, and Serer	Rainforest	19th-20th century	Agriculturalist: grains, groundnuts; Pastoralist: cattle	Agriculture	Skinner, 1973; Tymowski, 1991; Faye, 2013
SHO	South Africa	Wilton complex; Humansdorp, Knysna Heads, Oakhurst, Robberg Cave, Still Bay, and Great Brak River Cave	Savanna	Late Stone Age	Hunter gatherer: antelope, tubers, roots, small-medium terrestrial game	Hunter/ gatherers	Deacon and Deacon, 1999
SML	Shum Laka	Late Stone Age/Early Iron Age transition	Forest	9000-3000BP	Pastoralist: cattle; Hunter gatherer: early cultivation of yams	Pastoralists	Cornelissen, 1996; Lavachery, 1996; Ribot et al., 2001
SOM	Somalia	Hawiya, Darod, Digil, and Rahanwun	Desert	20th century	Pastoralist: cattle, camels, sheep and goats; some agriculture	Pastoralism	Konczacki, 1967; Farah and Lewis, 1997

Table 1. continued

SOT	Sotho	Koni and Tau	Savanna	20th century	Agriculturalist: maize, millet, pumpkins, and groundnuts; Pastoralist: cattle	Agriculture	Krige and Krige, 1954; Maylam, 1986; Zeleza, 1997
SPH	South Africa	Hetero-geneous sample	Savanna	>1600AD	Pastoralist: cattle	Pastoralism	Deacon and Deacon, 1999
SWZ	Swazi	Swazi	Savanna	20th century	Agriculturalist: maize, millet, pumpkins, and groundnuts; Pastoralist: cattle	Agriculture	Maylam, 1986; Zeleza, 1997
TAN	Tanzania and Zanzibar	Nyamwezi, Gnindo, Gogo, Guru, and some from Zanzibar	Savanna/ Forest	19th-20th century	Agriculturalist: sweet potatoes, bananas, and sorghum; fishing	Agriculture	Newman, 1970
TEI	Taita	Taita	Savanna	19th century	Agriculturalist: maize, beans yams, potatoes, taro, and cassava	Agriculture	Hambly, 1940; Fleuret and Fleuret, 1991

Table 1. continued

TOD	Togo and Dahomey	Ewe (Fon)	Rainforest	19th century	Agriculturalist: root plants, cola nuts	Agriculture	Manoukian, 1952; Mercier, 1954; Verdon, 1983
TSW	Tswana	Tswana	Desert	20th century	Pastoralist: cattle; Agriculturalist: maize, sorghum and sugarcane	Pastoralism	Maylam, 1986; Zeleza, 1997
TUK	Tukulor	Tukulor	Savanna	19th-20th century	Agriculturalist: millet, sorghum; Pastoralist: cattle and camels	Agriculture	Skinner, 1973; Tymowski, 1991; Faye, 2013
UPB	Upemba Valley	Kisalian culture (sites of Sanga, Kamilamba, Kikulu, etc.)	Savanna	1645+/-160to620+/-150BP	Agriculturalist: oil palm, yams, bananas, and beans	Agriculture	Oliver and Fagan, 1975; Maret, 1979
VEN	Venda	Venda	Savanna	20th century	Pastoralist: cattle; Agriculturalist: maize, sorghum and sugarcane	Pastoralism	Maylam, 1986; Zeleza, 1997

Table 1. continued

WOL	Wolmarans-stad	Mixed groups	Savanna	20th century	Agriculturalist: maize, millet and sorghum	Agriculture	Maylam, 1986; Zeleza, 1997
XOS	Xosa	Xosa	Savanna	20th century	Pastoralism: cattle	Pastoralism	Webster, 1986
YOR	Yoruba	Yoruba	Rainforest	19th century	Agriculturalist: root plants, cola nuts	Agriculture	Bascom, 1951
ZUL	Zulu	Zulu	Savanna	20th century	Pastoralist: cattle	Pastoralism	Chanaiwa, 1980; Ballard, 1981; Gump, 1988

Table 2. Number of individuals for each sample

Code	Male	Female	Unknown Sex	Total		Code	Male	Female	Unknown Sex	Total
ADR	1	3	4	8		NIC	28	17	8	53
CHA	20	7	4	31		NLT	10	11	0	21
CON	18	12	2	32		PYG	16	14	2	32
DBI	3	1	12	16		SAN	22	19	2	43
DCB	10	10	3	23		SEN	20	16	3	39
DCH	12	8	1	21		SHO	19	41	17	77
DCR	25	37	3	65		SML	1	0	4	5
ETH	15	15	5	35		SOM	57	16	1	74
FVR	23	18	3	44		SOT	47	18	0	65
GAB	18	15	1	34		SPH	32	17	16	65
GHA	29	14	3	46		SWZ	40	14	2	56
HAY	34	17	0	51		TAN	25	12	3	40
IBO	15	30	4	49		TEI	22	27	1	50
KEN	39	44	19	102		TOD	19	5	1	25
KHE	20	22	35	77		TSW	34	27	1	62
KHOI	29	11	9	49		TUK	26	6	5	37
KKU	44	12	1	57		UPB	9	16	22	47
LHK	6	18	43	67		VEN	46	4	0	50
MAT	12	15	16	43		WOL	18	4	2	24
NDB	30	6	1	37		XOS	46	14	2	62
NGO	6	6	13	25		YOR	17	9	1	27
NGU	25	5	5	35		ZUL	49	11	2	62
						Total	1037	644	282	1963

CHAPTER 4: METHODS

4.1 Data Recording Methods

All of the data were recorded by Irish (1993, 1997) and were used originally for his morphological studies. He also established the age and sex for each individual. The data were entered into the Predictive Analytics Software® (PASW®) 18.0 database (PASW, 2009) for easy accessibility, organizational purposes, and data analyses.

The location and severity are recorded for each of the caries present. Caries are ranked on a scale of 1 to 4 with 1 being a small pit that does not pierce through the enamel and 4 being pulp perforation (Buikstra and Ubelaker, 1994). Location is designated as mesial, distal, buccal, occlusal, or lingual. If numerous carious lesions exist on a single tooth, the highest severity value is recorded and a note is made indicating the presence of more than one carious lesion.

Sex is designated as either male, questionable male, unknown, female, or questionable female on the basis of cranial and skeletal morphological traits. For the purpose of this study male and questionable male were grouped together as were females and questionable females. Individuals designated as unknown sex are included in the study, but are kept as a separate category; thereby eliminating any misleading sex-based observations between males and females.

Each individual was assigned to an age category with 1 being a child between the ages of 0-6, 2 designating an age between 6-17, and 3 referring to 18 and older. The categories are based on ages when teeth erupt (permanent teeth began to come in at around 6 and finish at around 17). Only adults (category 3) are included in this analysis. Juveniles are excluded, not only because of their small sample sizes but also, because identifying the sex is difficult since sexual differences in the skeleton do not appear until sexual maturity (White, 2000).

Lukacs' (1992, 1996) caries index was calculated to adjust for antemortem tooth loss (AMTL). Many individuals had teeth missing antemortem (before death), and many other teeth were lost postmortem (after death). AMTL can occur as a result of accidental trauma, attrition, or the removal of tooth because of severe tooth pain (Lukacs, 1996). Many teeth are usually pulled because of a toothache resulting from serious carious lesions or even abscesses (Lukacs, 1996). Lukacs (1996) proposes a method to correct for AMTL by taking into account the number of teeth present that have pulp exposure (severity level 4) due to caries:

$$\frac{(\text{AMTL})(\text{percent of teeth with severe caries}) + (\text{teeth with caries})}{(\text{teeth present}) + (\text{AMTL})} \qquad \textbf{Eq. 1}$$

The Lukacs (1992, 1996) correction factor can be used to adjust for AMTL but not postmortem tooth loss. This analysis assumes that the caries information missing due to postmortem tooth loss is not significant and thus their exclusion will not have an effect on the results.

4.2 Analytical Methods

A variety of methods were used to analyze the data including graphs, Mann-Whitney U tests, factorial ANOVA (analysis of variance), and post hoc tests. Due to the large number of samples encompassed by the Recent category, tests are run on each time period separately and combined in order to obtain a more accurate representation of the data. All the results from the visuals and statistics were obtained through the Predictive Analytics Software® (PASW®) 18.0 database (PASW, 2009).

Caries severity and tooth wear data are ordinal (i.e. caries severity), dichotomous (i.e. male or female) and ratio (i.e. number of caries) level. In some instances, ordinal data are treated as continuous in statistical analyses for illustrative purposes only; that is, a grade 4 carious lesion can be interpreted to be twice as severe as a grade 2, which then emulates ratio level data (Irish, personal communication, 2013).

As with most statistical tests there are possible sources of error. Outliers may be a problem whenever the sample mean is used for analytical purposes. An outlier can consistently raise or lower the mean so that the average is not an accurate representation of the samples. An increase in sample size can help correct this inaccuracy. There are some samples that appear to be outliers for the current study, especially among the Recent samples (Figures 6-10). However, examining the reasons for abnormally high or low caries rates for each outlier are beyond the scope of the present study, instead the large sample size is assumed to correct for any major deviations from normality.

The Mann-Whitney U test is used in the present study because the data do not fully meet the assumptions for parametric tests (discussed in Results section). The Mann-Whitney U test is a non-parametric test that compares the differences between two independent samples by ranking their combined data values and then calculating the average rank for each group. The Mann-Whitney U test is used when the data do not meet the criteria or assumptions for an independent t-test (Mann and Whitney, 1947; Siegel and Castellan, 1988). For the current study the Mann-Whitney U test is used to compare each combination of groups within each variable (time period, subsistence strategy, environment, and sex) to determine whether there is any statistically significant differences.

The next logical step from Mann-Whitney U would be to run a Kruskal-Wallis test, but a factorial ANOVA test was used instead for several reasons. First, a Kruskal-Wallis test has limitations, for example the inability to run post hoc tests (Field, 2009). Second, this study also serves as a methodological exercise to show how results from Mann-Whitney U and factorial

ANOVA compare to one another. Third, factorial ANOVA provides more substantive results. Even though the factorial ANOVA test is a parametric statistic, the robusticity of the test will give reliable results even if the data does not meet all of the assumptions (Wilkinson, 1999; Gelman, 2005; Field, 2009).

A factorial (ANOVA) test is used to ascertain which (if any) variables have a significant effect on the frequency of caries. Where an independent t-test tests for any significant differences between independent variables, a factorial ANOVA determines which independent variables are responsible for driving the observed differences in the dependent variable. The factorial ANOVA is set up like a traditional ANOVA statistic, only there is more than one independent variable (Wilkinson, 1999; Gelman, 2005; Field, 2009). ANOVA statistics use the total sum of squared errors to calculate the variance that can be explained by the experiment and the variance that remains unexplained. Interactions between the variance of two or more independent variables are also explored in factorial ANOVA.

In order for factorial ANOVA to work accurately certain criteria should be met such as normality, homogeneity of the variances within a group, and the dependent variable data should also be interval level or higher (Scheffé, 1959; Field, 2009). Assuming that all the assumptions are met, a factorial ANOVA was calculated to determine significant differences between subsistence strategy, environment, time period, between the sexes, or any combination of these four variables on the dependent variable (percentage of teeth with caries per individual). More specifically, the independent factorial design is an appropriate statistical test because there are several independent variables (sex, environment, subsistence strategy, and time) that are being measured (Wilkinson, 1999; Freedman, 2005; Gelman, 2005; Field, 2009). The null hypothesis of consistency was tested followed by a series of post hoc tests (Tukey), in order to expose the significance between all combinations of the independent variables.

Spearman's correlation coefficient statistic was calculated to determine whether there is any relationship between attrition and caries. Spearman's test is a non-parametric test that is used to find if a relationship exists between two variables and the strength and trend of that relationship (Spearman, 1910; Field, 2009). Higher levels of wear should correlate with a lower number of caries because normal attrition wears away the tooth before caries can form (Brothwell, 1963; Scott and Turner, 1988; Hillson, 1996; Caselitz, 1998).

4.3 Conclusion

In summary, the Mann-Whitney U test is used to compare the percent of teeth with caries for each category of the independent variables to ascertain any significant differences. Factorial ANOVA is used to determine whether if any of the independent variables (time period, sex, environment, and subsistence strategy) have a significant effect on caries frequencies. Results from these tests will show which groups were affected most by dental and which factors have the greatest impact on the development of caries.

CHAPTER 5: RESULTS

5.1 Descriptive graphs

Several bar graphs were created to observe patterns before running any tests. Figure 5 shows the total percentage of males, females, and individuals of unknown sex affected by caries for each time period. Figures 6-7 represent the percentage of individuals with caries for males, females, and those of unknown sex by sample within each time period. Figures 8-10 show the percentage of males, females, and individuals of unknown sex by sample for each region. Figure 11 compares the different subsistence strategies against each other through time. Figure 12 illustrate the differences in caries by environment. Figures D-2 to 9 in Appendix D are similar to Figures 5-12 except they represent the average number of teeth with caries for each group.

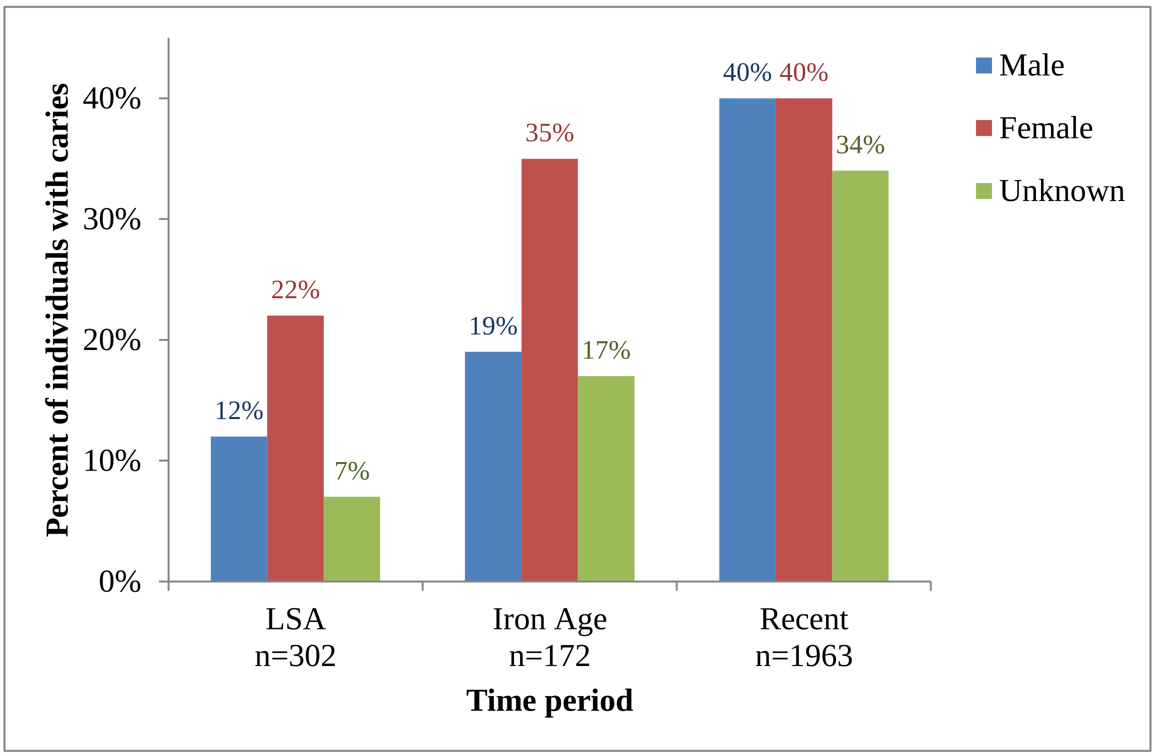

Figure 5: Percent of individuals affected by caries for each sex category for LSA, Iron Age, and Recent samples

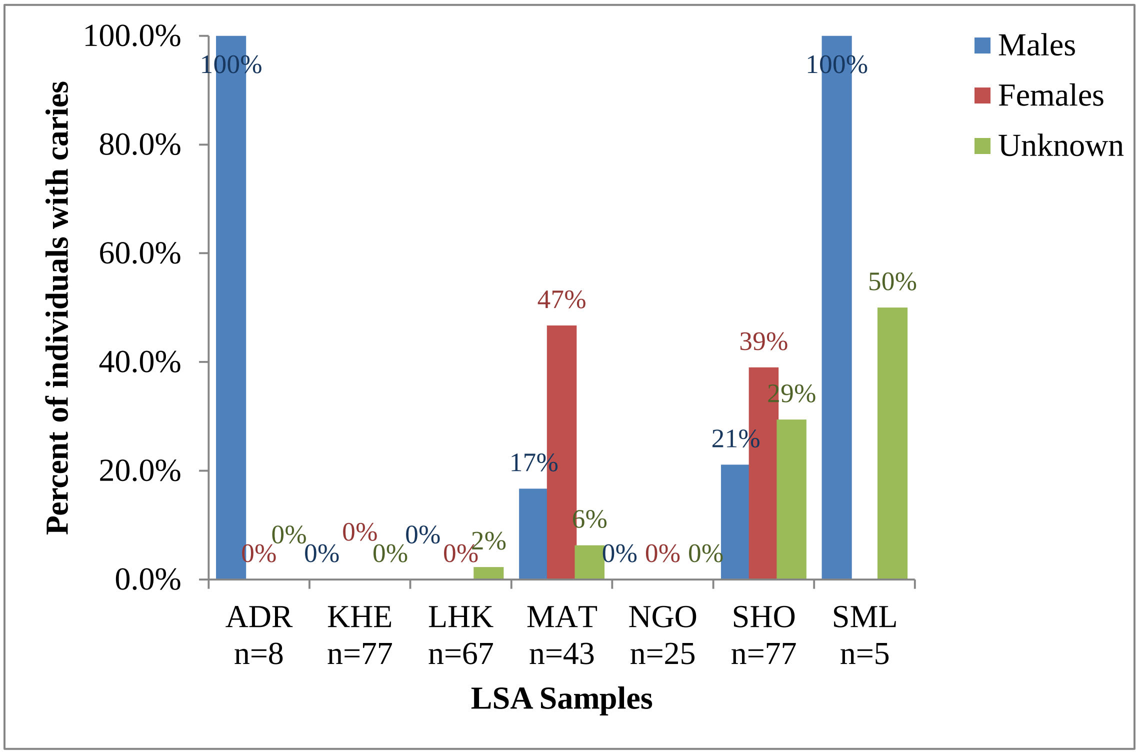

Figure 6: Percent of males, females, and individuals of unknown sex from LSA samples with caries

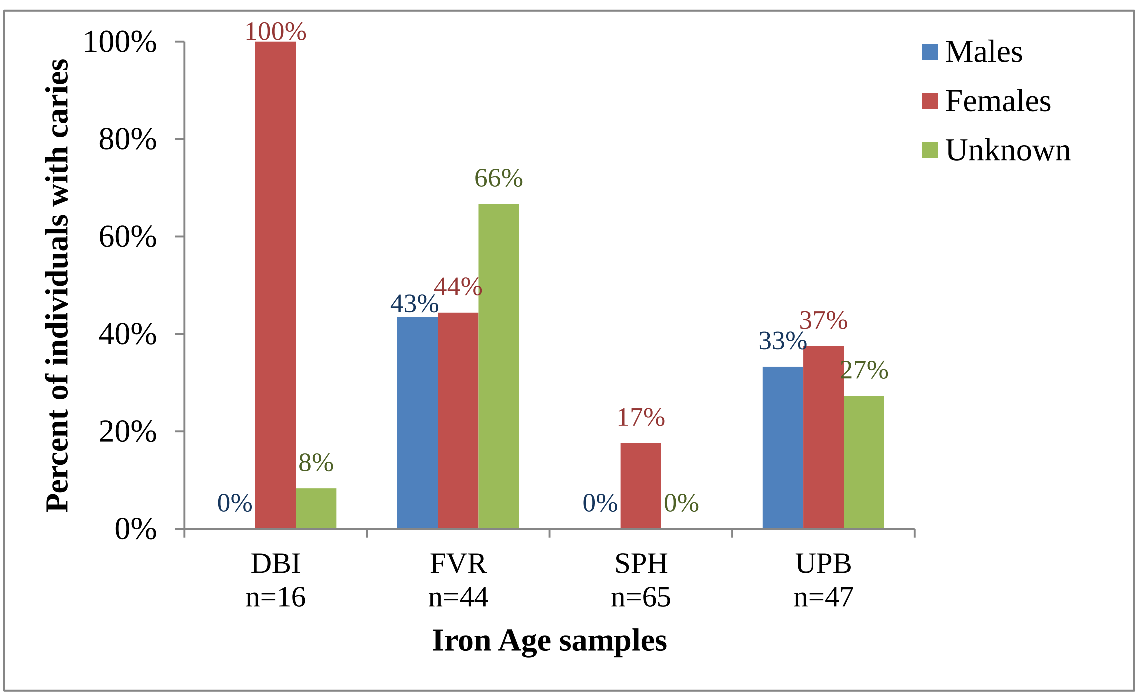

Figure 7: Percent of males, females, and individuals of unknown sex from Iron Age samples with caries

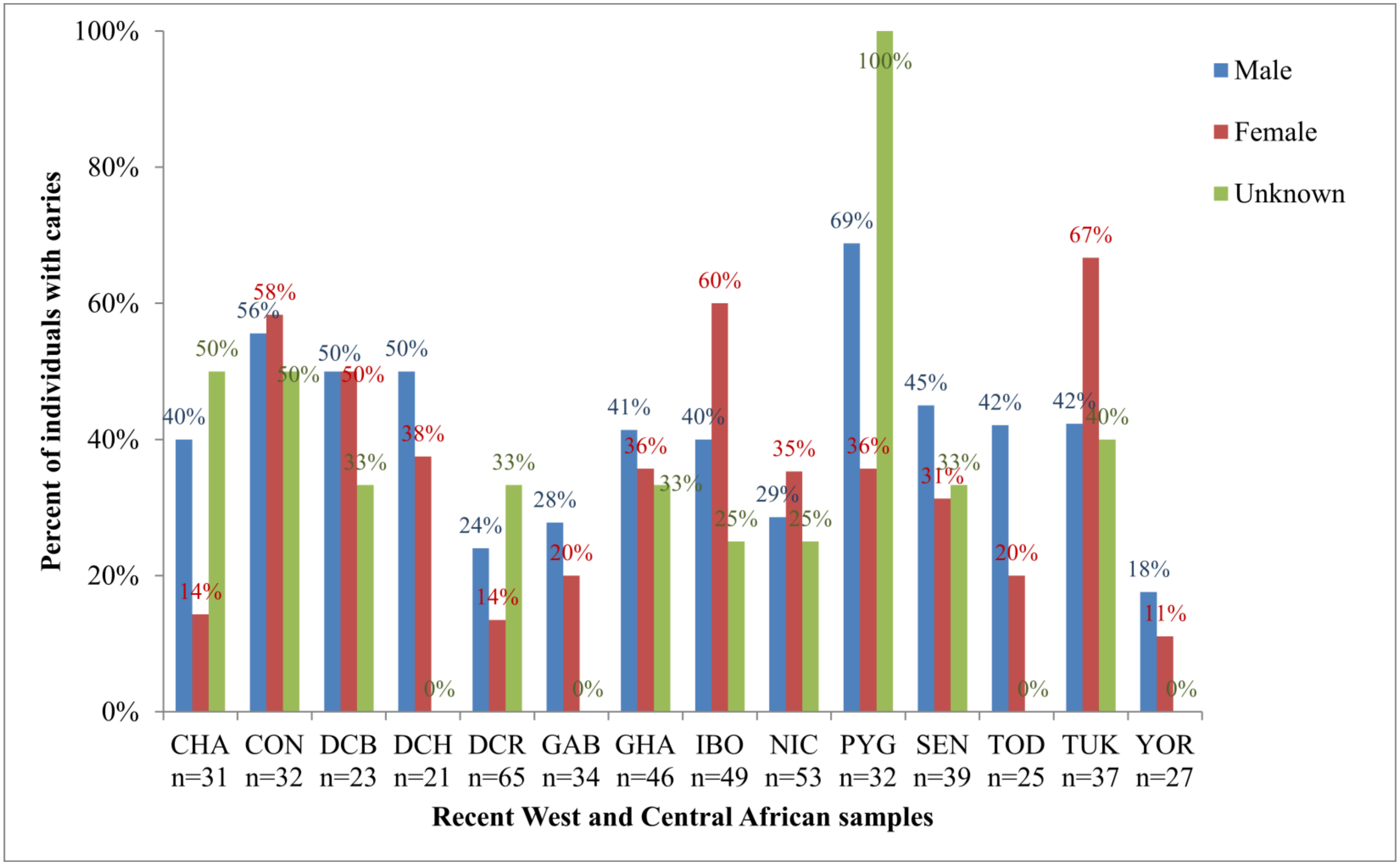

Figure 8: Percent of males, females, and individuals of unknown sex from Recent West and central African samples with caries

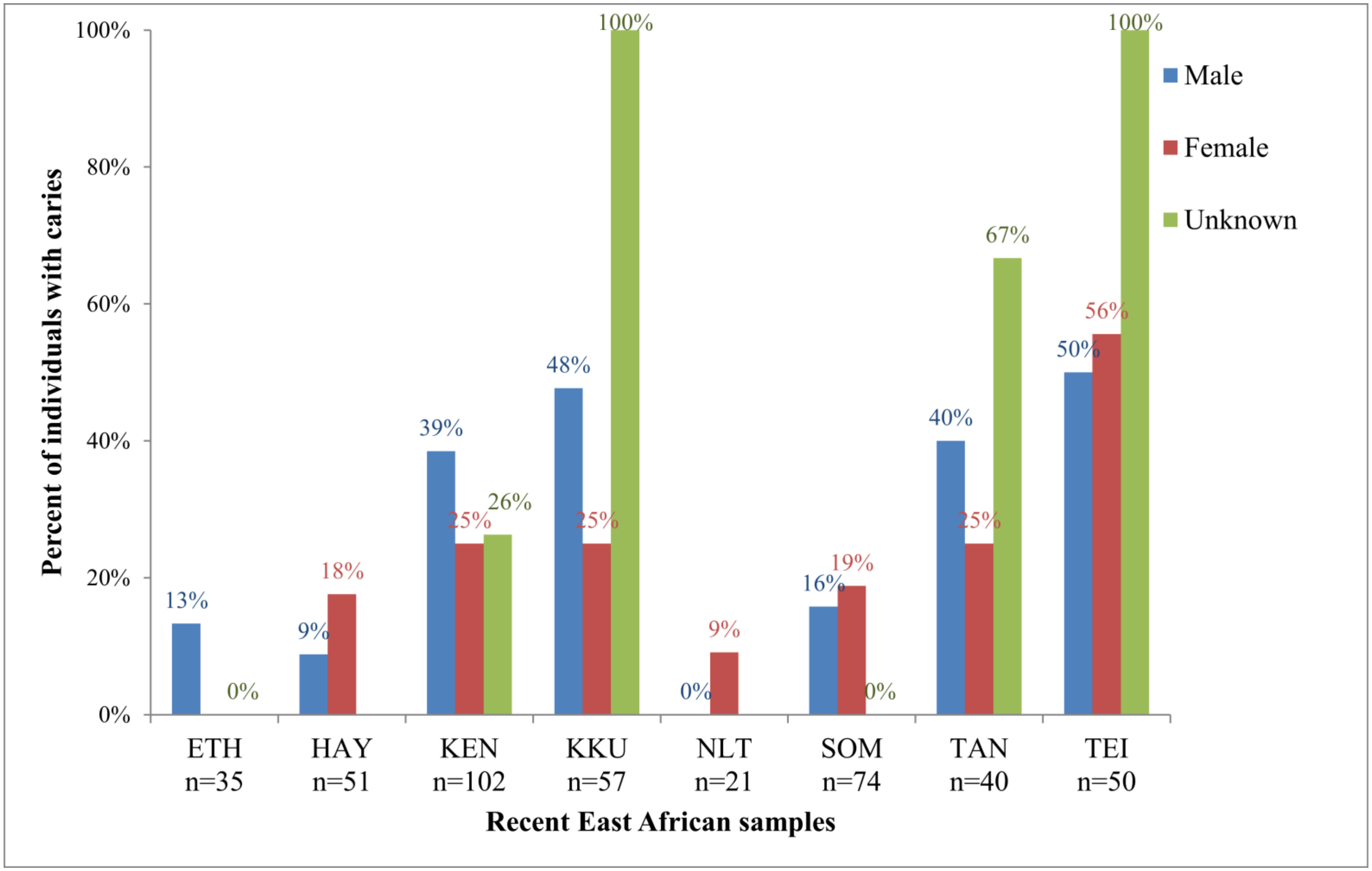

Figure 9: Percent of males, females, and individuals of unknown sex from Recent East African samples with caries

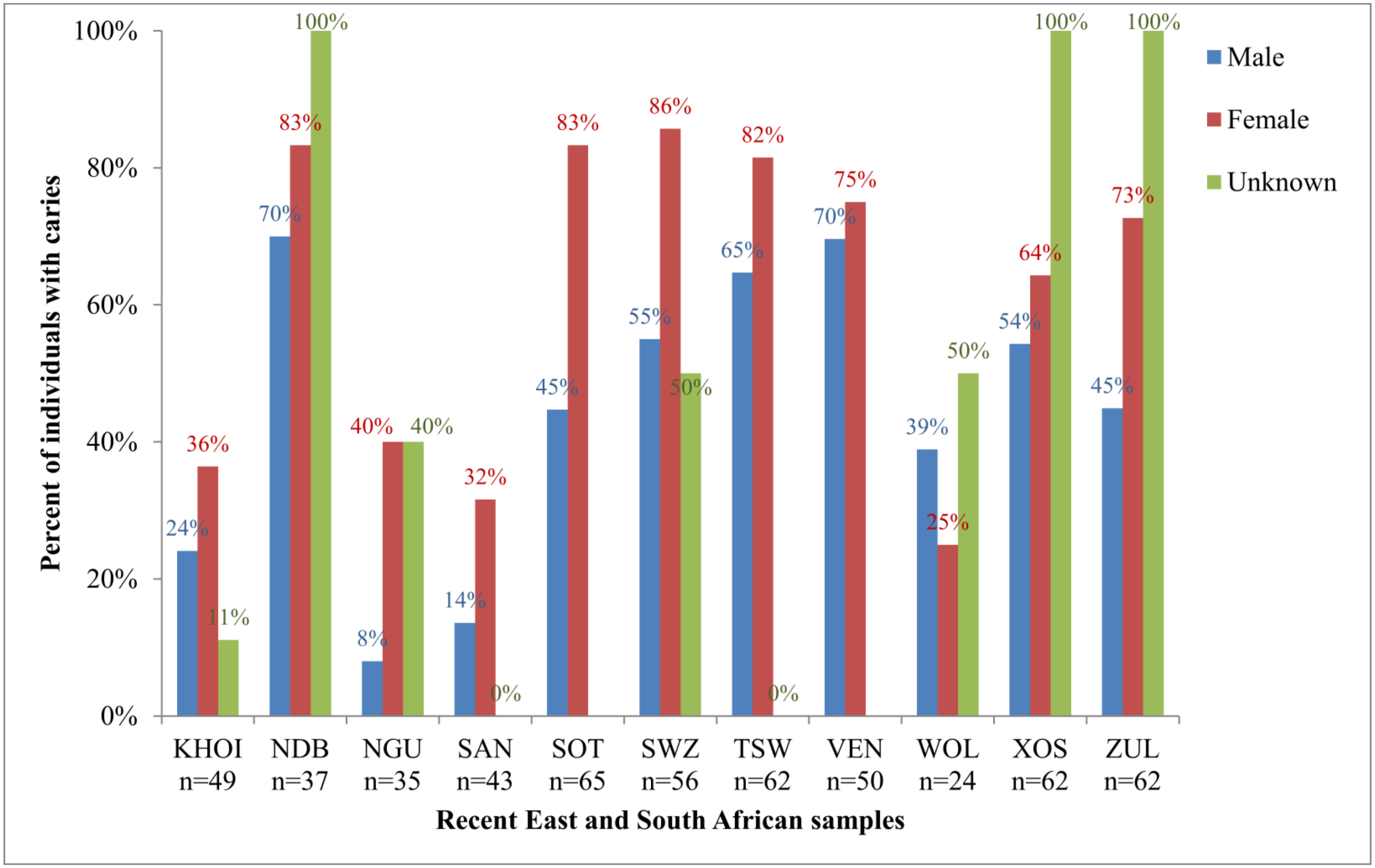

Figure 10: Percent of males, females, and unknown sex from Recent South African samples with caries

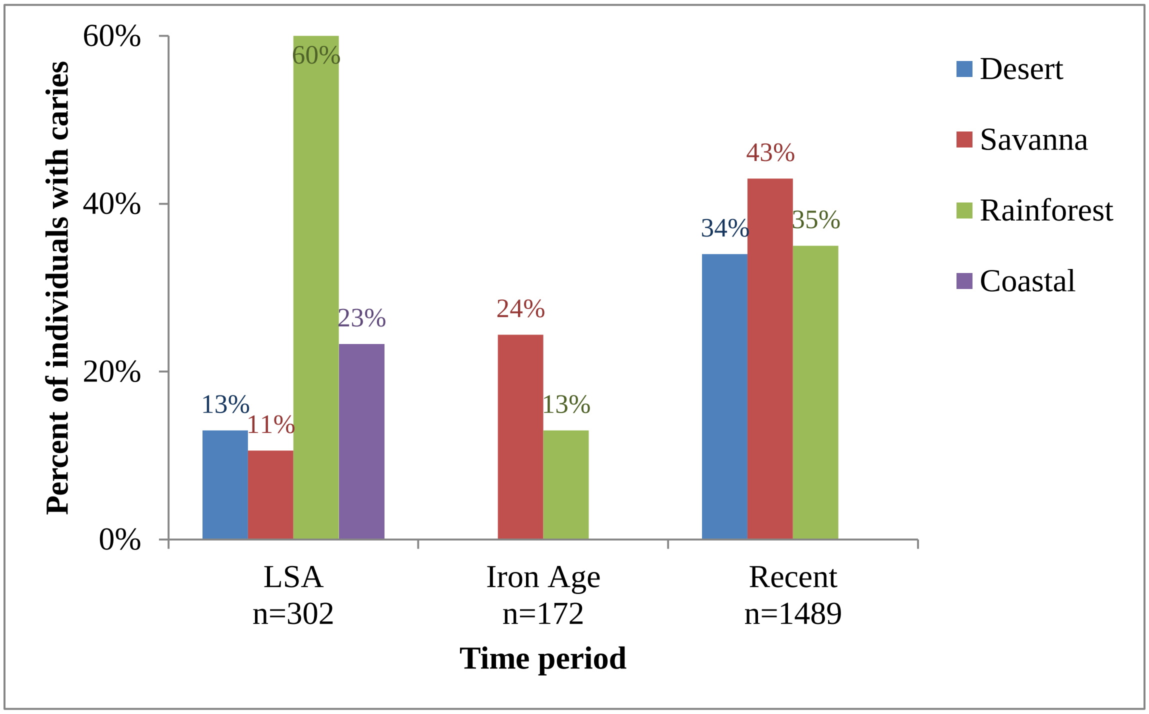

Figure 11: Percent of individuals affected by caries for each environment category in LSA, Iron Age, and Recent samples

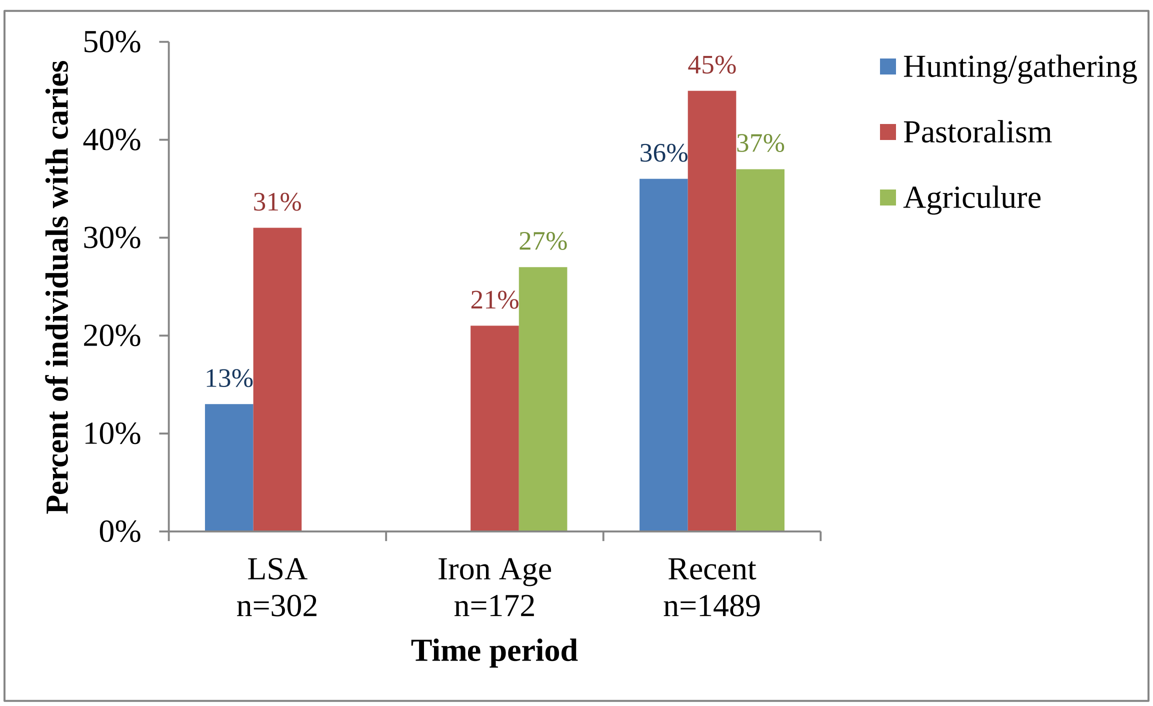

Figure 12: Percent of individuals affected by caries for each subsistence strategy in LSA, Iron Age, and Recent samples

5.2 Mann-Whitney U

Mann-Whitney U statistics (Table 3) were calculated with the goal of finding significant differences (α<.05) between the categories among each variable as well as exploring and checking the factorial ANVOA results. The Mann-Whitney U test results show a statistically significant difference between all the combinations of time periods, but there are no significant differences between the sexes for any time period. Half of the environments represented in the LSA are significantly different (savanna and rainforest, savanna and coastal, and rainforest and coastal). The Recent samples have significant differences between the desert and savanna groups, as well as the savanna and rainforest groups. When all the time periods are combined, hunting/gathering is significantly different from both agriculture and pastoralism, but no difference was found between agriculture and pastoralism. The two subsistence strategies present in the LSA, hunting and gathering and pastoralism, are also statistically different. In combination

Table 3. Results of Mann-Whitney U tests

		Significance			
Variable	**Groups**	**LSA**	**Iron Age**	**Recent**	**Combined**
Time Period	LSA & Iron Age	n/a	n/a	n/a	0.003
	LSA & Recent	n/a	n/a	n/a	0.000
	Iron Age & Recent	n/a	n/a	n/a	0.000
Sex	Male & Female	0.113	0.113	0.564	0.803
Environment	Desert & Savanna	0.942	n/a	0.016	0.625
	Desert & Rainforest	0.127	n/a	0.840	0.771
	Desert & Coastal	0.397	n/a	n/a	0.206
	Savanna & Rainforest	0.000	0.226	0.007	0.842
	Savanna & Coastal	0.018	n/a	n/a	0.131
	Rainforest & Coastal	0.031	n/a	n/a	0.162
Subsistence	Hunting/Gathering & Pastoralism	0.043	n/a	0.546	0.000
	Hunting/Gathering & Agriculture	n/a	n/a	0.975	0.000
	Pastoralism & Agriculture	n/a	0.510	0.134	0.654

with the Mann-Whitney U tests, a series of independent t-tests were run; results are shown in Table F-2 of Appendix F.

5.3 Factorial ANOVA

Tables 4 and 5 show the results of the factorial ANOVA. Levene's test (Table E-1 in Appendix E) was calculated to test the assumption of homogeneity of variance and the result of 0.000 indicates the assumption of homogeneity of variance has not been met. The assumption of normality is also not met because all of the data are skewed toward 0 (Figure E-10 in Appendix E). Considering how robust ANOVA is, violating the assumption of homogeneity of variance should not greatly alter the results, but they should be interpreted with caution (Wilkinson, 1999; Gelman, 2005; Field, 2009).

Table 4 is the main table for factorial ANOVA. Significant values (<0.05) designate that the corresponding variable has a statistically significant effect on the frequency of caries. Both time period and sex were found to have no significant values. Environment has a significant effect for LSA, Recent, and combined time periods. Subsistence has a significant effect on caries rates only when all of the time periods are combined.

Results for Tukey's post hoc tests are shown in Table 5. Post hoc tests are used to compare the categories within the individual variables. The Recent groups are statistically significant (<0.05) from both the LSA and Iron Age groups. There are no statistically significant differences between the sexes for any of the time periods, including when they are all combined. Only the LSA time period had any significant values between environments (desert and rainforest, savanna and rainforest, rainforest and coastal). Subsistence strategies are only significant when all the time periods are combined, hunting/gathering and pastoralism are significantly different (0.002) as are hunting/gathering and agriculture (0.000).

Table 4. Factorial ANOVA results

	LSA	Iron Age	Recent	Combined
Time Period	n/a	n/a	n/a	0.349
Sex	0.082	0.675	0.708	0.836
Environment	0.000	0.609	0.009	0.004
Subsistence	n/a	0.789	0.069	0.037

Table 5. Tukey results

		Significance			
Variable	**Groups**	**LSA**	**Iron Age**	**Recent**	**Combined**
Time Period	LSA & Iron Age	n/a	n/a	n/a	0.057
	LSA & Recent	n/a	n/a	n/a	0.000
	Iron Age & Recent	n/a	n/a	n/a	0.041
Sex	Male & Female	0.295	0.415	0.327	0.500
Environment	Desert & Savanna	0.965	n/a	0.156	0.941
	Desert & Rainforest	0.000	n/a	0.538	0.583
	Desert & Coastal	0.607	n/a	n/a	0.639
	Savanna & Rainforest	0.000	n/a	0.682	0.679
	Savanna & Coastal	0.255	n/a	n/a	0.424
	Rainforest & Coastal	0.000	n/a	n/a	0.243
Subsistence	Hunting/Gathering & Pastoralism	n/a	n/a	0.323	0.002
	Hunting/Gathering & Agriculture	n/a	n/a	0.752	0.000
	Pastoralism & Agriculture	n/a	n/a	0.236	0.125

5.4 Spearman's Correlation Coefficient

The correlation between wear and caries prevalence was calculated using Spearman's Correlation Coefficient (Table 6). A one-tailed test was selected with the expectation that as wear increases; the number of caries should decrease. The positive correlation coefficient (0.129) indicates a very small positive relationship, meaning that as the number of caries increases so does the severity of the wear. The low significance value (0.00) indicates that the coefficient value represents a true relationship.

Table 6. Spearman's Rho

Correlation Coefficient	0.129
Significance	0.000

5.5 Conclusion

Results from the graphs, non-parametric Mann-Whitney U tests, and parametric factorial ANOVA and Tukey test, are fairly consistent. The only major inconsistency concerns the variable of time period, where the Mann-Whitney U results shows significant results, which the results obtained by factorial ANOVA found time period to not be a significant factor contributing to caries frequencies. Apart from the contradiction with the time period variable, all tests show that sex differences in caries are not significant, but that environment and subsistence strategies are important factors contributing to the prevalence of dental decay.

CHAPTER 6: DISCUSSION

6.1 Did caries frequencies change through time?

Figure 5 shows that there is a definite increase in caries prevalence through time. Tukey tests (Table 5) yield significant results for the LSA and Recent, and Iron Age and Recent pairing, whereas the Mann-Whitney U test (Table 3) provides significant values for each pairing of time periods. Factorial ANOVA (Table 3) found that time period was not a significant factor for caries prevalence. The inconsistent finds between the Mann-Whitney U test and factorial ANOVA are not surprising given the differences in how the results are calculated. For the current study, the possibilities for the significant values provided by the Mann-Whitney U tests and Tukey tests are discussed below.

Dramatic dietary changes in various parts of the sub-continent may be responsible for the temporal differences in caries. Many new crops were introduced into the sub-Saharan diet that may have impacted dental health. In particular, Asian crops such as sugarcane and bananas spread through diffusion or were introduced by the Portuguese in the 17th century.

Sugarcane has a negative impact on dental health. Not only does the plant have a high amount of sucrose, but the manner in which it is eaten wears away the teeth. Irish and Turner (1997) found increased instances of lingual surface attrition of the maxillary anterior teeth (LSAMAT) and high carious tooth counts among people in Senegal. The consumption of sugarcane, manioc, or both is the suspected cause. Both are peeled and shredded with the front teeth then sucked on, which produces the unique LSAMAT and the simple sugars mixed with the starches cause the higher frequency of carious lesions. Other researchers have also found that sugarcane chewers in Kenya and Tanzania have high instances of carious teeth (Dreizen and Spies, 1952; Frencken et al., 1989).

Bananas and plantains were brought from Asia to Africa as early as the Iron Age. Bananas were and continue to be a significant crop in central and eastern Africa because they are resistant, produce high yields, and require little labor (Ehret, 2002; Collins and Burns, 2007). An average of 250kg of bananas and plantains are eaten per individual every year in some parts of Africa (Reader, 1997; Aurore et al., 2008). Numerous studies have shown the cariogenic quality of bananas as a result of their sticky and sugary nature (Barmes, 1968; Mundorff et al., 1990; Mundorff-Shrestha et al., 1994; Aurore et al., 2008).

Several new crops were introduced after the discovery of the Americas, including maize, cassava, and tobacco; all of which have cariogenic properties (Larsen et al., 1991; Hillson, 1996; Winn, 2001; Ehret, 2002). Maize in particular can greatly increase caries frequencies because it is a grain that contains 2-6% sucrose (Larsen et al., 1991). Maize spread quickly throughout the sub-continent due to its ability to grow in the forest where most other grains cannot. Cassava, a tuber, also spread rapidly because of its capability to survive droughts and thus grow in the savanna. Most American crops did not become widespread in sub-Saharan Africa until the 18th century and this late spread may partially account for the rise in caries between the Iron Age and Recent samples (Ehret, 2002).

With the arrival of Europeans, sub-Saharan Africa went through dramatic events such as the slave trade, war, and widespread displacement (Reader, 1997; Ehret, 2002; Moradi, 2009). Psychological stress, including depression and anxiety, have been linked to higher occurrences of dental caries, periodontal disease, and tooth loss (Cohen and Williamson, 1991; Honkala et al., 1992; Vered et al., 2011). Vered et al. (2011) compared psychological distress to caries in Ethiopian immigrants and determined that there is a positive correlation between stress and oral health. In comparison with their baseline, Vered et al. (2011) calculated that distressed individuals had 3.52±0.19 caries whereas, non-distressed individuals only had 0.35±0.15 caries. Such results indicate clearly that stress has a significant impact upon dental decay.

Changes brought about in the mid-19th century to present have had an overall negative impact on oral health (Steyn, 2003; Raschke and Cheema, 2007; Moradi, 2009). The soft sticky high-carbohydrate foods common in an agriculturalists' diet are more carious than the tough fibrous foods of the traditional African diet (Newbrun, 1982; Hillson, 2008). Furthermore, the introduction of heavily processed foods has accentuated the decline in oral health.

6.2 Is the rate of caries higher among women than men?

Factorial ANOVA results indicate that sex does not contribute significantly to caries frequencies (Table 4). Mann-Whitney U (Table 3) and Tukey tests (Table 5) also show that there is no statistically significant difference in caries between males and females for any time period. However, Figure 5 displays a general trend of more females with caries for both LSA and Iron Age samples. In the Recent samples, males and females have equal percentages of individuals affected by caries. Recent females have a slightly higher average number of teeth with carious lesions (Figure D-2 in Appendix D), but this difference is not as pronounced as those observed in the other groups. Researchers have reported that agriculture typically accentuates sex differences in dental decay, however the sub-Saharan samples challenge this claim (Lukacs and Largaespada, 2006; Lukacs, 2008; Watson et al., 2010). In order to determine why a trend seen worldwide does not apply to modern sub-Saharan Africans, a closer examination of the samples is provided below.

The Recent western and central African groups (Figure 8) are comprised primarily of samples that have more males with caries (9 out of 14). In general, the samples with higher caries counts are comprised of individuals from the rainforest who practice agriculture. The individuals comprising the samples from eastern Africa (Figure 9) where more males have caries practice agriculture and primarily live on the savanna. A Mann-Whitney U test was run to determine if any statistically significant difference exists between males and females from the rainforest and males and females from agricultural societies. The results show that there are no significant differences between the sexes regardless of agricultural (0.830) or rainforest (0.321) ecological settings.

Figures 8-10 show that the samples where caries prevalence is higher among females are those who practice a mix of pastoralism and agriculture and live on the savanna. Females also have a higher average of carious teeth within their mouths (Figure D-3 to 7 in Appendix D). Mann-Whitney U tests were run to compare males and females that practice pastoralism and found that there is a statistically significant difference (0.027). The same test was used to compare males and females that live in the savanna, but the results show there is no difference (0.528).

Even though Figures 8-10 show some distinctive patterns, only males and females using pastoralism show a significant difference in caries counts. The often grain-dependent pastoralists rely on foods that are cariogenic both raw and cooked. Because females collect and prepare the foods (in pastoralist communities the men may do most of the milking, but women process all of the foods) they are likely to consume more of the cariogenic foods (Mulder, 1992).

Even if the difference in caries frequencies between males and females who live in the rainforest is not statistically significant, possible explanations to rationalize the higher instance of male caries, as observed in Figures 8 and 9, are examined. Of the samples comprised of individuals from the rainforest, the pygmies (PYG) are the only non-agricultural people with worse male dental decay though this might be explained by their trade for food with their Bantu neighbors (Afolayan, 2000). For males to have consistently more caries is rare for any time period, subsistence strategy, or environment (Turner, 1979; Watson et al., 2010; Gamza and Irish, 2012).

In the majority of samples where males have more caries, root crops such as yams and taro as well as bananas and plantains are the dietary staples. As discussed above, bananas promote caries in a variety of ways. In general men are responsible for starting the banana garden and may take part in the more labor intensive aspects of growing bananas (Reader, 1997; Maruo, 2002). However, females are mainly in charge of caring for and harvesting bananas and plantains (Reader, 1997).

Additionally, cooked yams and taro are very cariogenic. Lingstrom et al. (2000) and Valentin et al. (2006) found that the cooking of starchy foods, such as yams and taro, greatly contributes to the development of dental caries because the cooking process softens them, creating a sticky texture that is more likely to adhere to the teeth. Cooking also breaks down the starches making them more easily digestible for bacteria. Several case studies have found that the introduction of tubers and roots in the diet results in an increase in carious lesions throughout the population (Walker and Erlandson, 1986; Irish and Turner, 1997).

One possible explanation for higher caries counts in men who rely on root crops might have to do with gender roles. In root crop dependent cultures, females are responsible for collecting the crops. Perhaps, females have fewer caries because they consume unprocessed foods as they gather them; whereas the males eat more of the cooked cariogenic forms of the foods prepared for them. Females might not eat as much of the processed foods after having snacked on raw foods all day and, thus would not be as affected by the prepared roots. If cooked starchy roots are indeed to blame for higher instances of male caries then sexual division of labor may well be the main factor for unbalanced caries counts between the sexes. However, this scenario is problematic in that many of the roots are poisonous or inedible if not processed. Perhaps, females find other sources of food to snack and fill up on.

The effects of fertility on the frequency of carious lesions for sub-Saharan Africans cannot be thoroughly analyzed due to the lack of fertility studies for the region. Lukacs (2008) proposes that increased fertility among women with the advent of agriculture is partially responsible for higher prevalence of caries among females. If true, then females in the rainforest might have fewer caries compared to their male counterparts because they are less fertile than in regions where females consistently have more caries. A number of factors affect fertility including: infertility, an unstable marriage, extended periods of breastfeeding, high sex ratios, malnutrition, etc. (Mosher, 1979; Mulder, 1992). Major events such as the slave trade and King Leopold's reign could also have affected fertility because of the increased amounts of stress and dietary changes.

Because males are just as likely to be more affected by caries than females, biological factors such as hormones and genetics (as discussed in the Materials and Methods chapter), have no bearing on the Resent sub-Saharan samples. If genetics or hormones played a major role in female susceptibility to dental disease, than females would always have a higher instance of caries and not just those who practice pastoralism. Other studies show little to no differences in carious teeth between the sexes within a population (Campbell, 1938; Larsen, 1983; Walker et al., 1998; Douglas, 2006; Temple and Larsen, 2007). If biological factors play a role in caries development then a more universal trend would be expected.

6.3 Are there environmental differences in caries frequencies throughout sub-Saharan Africa?

Factorial ANOVA results show that only when all the time periods are combined (0.004) does environment have a significant impact on caries (Table 4). Both the Tukey and Mann-Whitney U results reveal that there is no significant difference between the environments in terms of caries counts for the Iron Age samples, but that some differences are present among the LSA and Recent samples (Table 5 and Table 3). Observing environmentally-based patterns in Figure 11 is difficult because not all of the environmental groups are present for each time period.

In both the Iron Age and Recent samples, caries are more prevalent among those who live in a savanna setting. A vast majority of savanna residents rely either on grains or pastoralism. Pastoralists often trade with agriculturalists for grains, which are commonly cooked into porridge (Forde and Jones, 1950; Ottenberg and Ottenberg, 1960; Skinner, 1973). Porridge is more likely to settle into the fissures and grooves of teeth making these hard to clean places a perfect place for plaque forming bacteria to reside (Larsen, 1995). Okazaki et al. (2013) found that the millet dependent Bunun of Taiwan had a higher prevalence of caries than their non-millet-dependent neighbors. In a comparison of wheat, corn, rice, and oats, Dodds (1960) concluded that both wheat and corn have the highest cariogenicity. As a result of the savanna inhabitants' reliance on grains, they developed increased instances of carious lesions.

Table 11 also shows a high percentage of caries (23% of the individuals) among coastal LSA samples (the rainforest sample for LSA is only comprised of 5 individuals). People on the coast generally have fewer caries because of the increased grit and higher amounts of fluoride from marine foods (Walker and Erlandson, 1986; Sealy et al., 1992). Sealy et al. (1992) had similar results with individuals from Oakhurst on the Southern Cape of South Africa. Contradictory to their results with other coast dwellers, where only 2.6% of the teeth had caries, 17.7% of the teeth from Oakhurst had caries. Oakhurst inhabitants ate a great deal of marine resources including fish and gastropods. The authors believe the only explanation for the high percentage of caries is the lack of fluoride in the natural ground water in the area. Fluoride is reported to have concentrations below 1 ppm today and may have had equally low amounts during the LSA (Sealy, et al. 1992). The LSA coastal sample, MAT, is very close to Oakhurst and could have correspondingly low fluoride levels which would explain the abnormally high percentage of caries.

6.4 Does subsistence strategy affect dental health?

The results obtained by factorial ANOVA suggests that subsistence strategy is a contributing factor to caries counts when all of the time periods are combined (Table 4). Subsistence strategy directly affects what people eat; hunter/gatherers eat wild unprocessed plants and animals, pastoralists rely mainly on the byproducts of their livestock and grains from neighboring agriculturalists and agriculturalists rely on processed grains and tubers. For subsistence strategy not to be a major contributing factor in the prevalence of caries would indicate that diet is not a factor in tooth decay, which would contradict everything researchers know about the etiology of caries.

Outcomes from the Tukey and Mann-Whitney U (Table 5 and Table 3) tests show a significant difference between hunter/gatherers and pastoralists, and hunter/gatherers and agriculturalists in the LSA samples and when all the time periods are combined. There is no significant difference in the number of caries between pastoralists and agriculturalists. For reasons discussed below, a similarity between the pastoralists and agriculturalists is not surprising.

There is no discernable pattern in Figure 12 for subsistence strategy; this might be a result of not all of the subsistence strategies are present for each time period. However, the larger percentage of individuals with caries in Resent pastoralists is interesting. As discussed previously, pastoralists also consume a lot of grains in addition to milk and other livestock byproducts (Forde and Jones, 1950; Ottenberg and Ottenberg, 1960; Skinner, 1973). Also, many of the Recent pastoralists are agro-pastoralists, meaning that they grow crops and keep livestock (Krige and Krige, 1954; Ottenberg and Ottenberg, 1960; Skinner, 1973; Clark, 1980; Zeleza, 1997). The traditional grain porridge combined with cariogenic new crops such as maize, which is commonly consumed by pastoralists, obviously had a negative impact on dental health (Larsen et al., 1991; Scherer et al., 2007). The newly introduced tuber, cassava, would also have been a new source of starch (Ehret, 2002). The sticky starches from cassava consumed with the carbohydrates from the grains create a perfect environment for bacteria. The starch prevents the carbohydrates from being immediately cleaned away, thereby giving bacteria more time to feed (Newbrun, 1982; Lingstrom et al., 1989, 1993; Larsen, 1997; Hillson, 2008).

The effect of cow's milk on dental health is generally positive, unless milk is consumed frequently. In toddlers and other animal species, milk has been observed to prevent or have no effect on caries (Peres et al., 2002; Bowen and Lawrence, 2005; King et al., 2006). The potentially cariogenic lactose is negated by the calcium and other vitamins found in milk. However, Bowen and Pearson (1993) found that if streptococci are frequently exposed to lactose, lactose fermentation can increase. In pastoralist communities where milk is consumed daily, the bacteria adapt in order to consume more lactose effectively causing more caries.

MacDonald's (1996) study of pastoralists from Somalia revealed a surprisingly high instance of caries as well. Modern Somalis drink large amounts of tea with both milk and sugar. MacDonald (1996) believes that the increased amounts of sugar put in the tea are responsible for the carious lesions. The amount of sugar consumed by each of the modern pastoralist samples is not known, but the introduction of sucrose into the diet definitely has a negative impact on oral hygiene.

Figure 12 also shows a comparable amount of individuals with caries in Recent hunter-gatherers and agriculturalists, with hunter-gatherers having a higher mean number of caries per individual. Perhaps this similarity is related to the fact that modern day hunter-gatherers, like the San, are not as isolated from other people as they used to be. After the arrival of the first European settlers, many Khoisan were forced into working on large farms. As a result, they were forced to eat domesticated crops rather than wild plants (Reader, 1997; July, 1998). Modern San often depend on food from government surplus, gardening, and food from nearby pastoralists in addition to their traditional hunting and gathering (Draper and Kranichfeld; 1990). Modern pygmies (PYG) rely on nearby agriculturalists for trade, which often includes food products (Afolayan, 2000). The increase in domesticated and processed foods has caused the San and pygmies to have similar caries rates to those of agriculturalists. Due to their location, one might attribute the high caries rates in the San with low fluoride levels, like the MAT sample. However, Sealy et al. (1992) note that the Kalahari Desert, where most San reside, actually has relatively high amounts, between 1-6 ppm, of fluoride in the ground water.

Figure D-9 in Appendix D shows a higher average of teeth with caries in hunter-gatherers compared to pastoralists and agriculturalists only in modern groups. Caries are an infectious disease and once present in the oral cavity, they can spread to other teeth quickly if not treated

(Hillson, 1996). The raw data shows that not only are a high number of individuals infected with caries, but the individuals with caries have a relatively high number of teeth infected indicating that unchecked plaque-causing-bacteria spread to other teeth.

In comparison with Turner's (1979) meta-analysis of populations with different economies, the sub-Saharan results are fairly similar. Turner reports a range of 0.0-5.3% for hunter-gatherers. The sub-Saharan LSA samples fall within this range (2%) but not the Recent hunter-gatherers (8%). The majority of Turner's populations come from archaeological sites older than the Recent samples, so there is not as much influence from agriculture. However, the Recent hunter-gatherers do fall within Turner's range for mixed economies (0.4-10.3%), which would probably be a more adequate description for modern hunter-gatherers. Sub-Saharan pastoralists (5-7%) fall within the mixed economy category. The agriculturalists (4.0-7%) fall within range of Turner's agriculturalists category (2.3-26.9%).

6.5 Other Observations

Figure 10 shows that a higher number of individuals had more caries in the Recent South African samples when compared to the other Recent samples. One explanation is low fluoride levels in the drinking water, as discussed by Sealy et al. (1992), but not all of the samples are from the fluoride deficient zone of South Africa. Another explanation is the kind of crops grown; which include maize, sugarcane, and grains (Lye, 1969; Maylam, 1986; Zeleza, 1997). As discussed previously, the simple sugars from maize and sugarcane combined with the grains can have a negative impact on dental health. Other possible factors might be dental hygiene practices, habits (such as tobacco use), and even genetics.

Comparing specific samples raises the question of why some LSA samples have a higher percentage of caries than some Recent samples. For example, why does the NGU sample have percentages comparable to the SHO sample? As described in previous chapters and as seen from the current study's results, caries are a complex disease influenced by several factors, and with a sample sizes as large as the one presented here, there are bound to be some outliers or unexplainable outcomes (discussed in Chapter 4).

In comparison with Shaw's (1931) findings, this study found much higher instances of carious lesions among the Bantu. The average number of caries per individual for Shaw's Bantu samples were 2.08% for males and 2.51% for females. These were compared with the Recent South African samples which, with a few exceptions, had consistently higher percentages of teeth with caries. However, Shaw's data is skewed because his sample came from a dentist's clinic, implying that participants in the study cared for their oral health and took care of carious lesions before the disease could spread to other teeth.

6.6 Is there a correlation between wear and caries?

The very small positive correlation (0.129) between caries and wear was unexpected (Table 6). Generally, a negative correlation is seen, meaning that as wear increases the number of caries decreases due to the plaque and carious lesions being worn away before they become serious (Brothwell, 1963; Scott and Turner, 1988; Hillson, 1996; Caselitz, 1998). The absence of any strong correlation is probably the result of two factors. First, all the adult individuals were pooled together. A pattern might become more apparent if the adults were divided into age-based categories. Both caries and wear are age related; higher frequencies of caries and severe wear become more common as an individual ages (Hillson, 1996). The chances of caries developing increases with age because plaque has had a longer time to develop and enamel may have worn away exposing the softer dental tissues. Attrition increases with age because natural processes, such as eating, continuously wear away the tooth. Dividing adults into smaller age-based categories would provide a better chance of finding any patterns (Brothwell, 1963; Scott and Turner, 1988; Hillson, 1996; Caselitz, 1998).

Secondly, even if wear was constant, caries could form on areas of the tooth that are not quickly worn away. Wear mainly affects the occlusal surface of the tooth thus this area wears away the fastest, but areas that are not constantly in contact with food or other teeth will not wear away as quickly. Areas that do not wear away provide a more stable environment for bacteria to grow (Hillson, 1996).

6.7 Summary

Statistically significant differences in caries frequencies have been observed between time periods, between environmental groups, and subsistence strategies. These differences are the direct result of dietary differences. The introduction of new foods, regional specialization, and food collecting strategies effect what people eat which in turn affects dental health. Results suggest that biological factors probably do not play a major role in tooth decay between males and females. The results from the current study imply that cultural differences can have major ramifications for dental health.

CHAPTER 7: CONCLUSION

7.1 Overview

Sub-Saharan Africa encompasses a large and diverse population. Within the past 10,000 years, the people of Africa have been subject to major changes that greatly affected their lifestyles and health. The LSA was the start of major cultural diversity for many African cultures. Rudimentary crop and livestock domestication spread to parts of western and eastern Africa (Clark, 1962; Ambrose, 1998; Marshall, 2000; Barham and Mitchell, 2008). Climatic change triggered new forms of technology to cope with the oscillating environment (Clark, 1969). LSA human ingenuity sparked one of the biggest and most revolutionary cultural expansions in world history.

The Bantu Expansion forever changed the economy, language, political system, and overall way of life for the majority of sub-Saharan Africans (Greenberg, 1972; Afolayan, 2000; Ehret, 2002). Originating in Cameroon, Bantu-speaking people dispersed a variety of technologies including iron use, agriculture, pottery, and, in later phases, pastoralism (Soper, 1982; Afolayan, 2000; Ehret, 2002; Phillipson, 2005).

Starting in the 16th century, Europeans began to colonize the sub-continent. Their presence triggered large-scale migrations, wars, trade of both slaves and valuable resources, and large-scale economic change (Reader, 1997; July, 1998; Collins and Burns, 2007; Raschke and Cheema, 2007). Most Africans were affected in some way by the arrival of Europeans.

The LSA, Bantu Expansion (Iron Age), and post-European contact (Recent) phases have all resulted in major changes to the diet. LSA individuals mostly relied on hunting and gathering with some simple domestication. During the Iron Age, people began to rely on agriculture for their subsistence but still subsidized with some foraging. In Recent times agriculture and pastoralism dominate the economy with very few true hunter-gatherers remaining.

Major dietary shifts impacted dental health. In the case of the present study, dental caries were examined for each time period using a series of graphs, factorial ANOVA, Tukey post hoc tests, and Mann-Whitney U tests to determine trends in the dietary shifts among the sub-Saharan African people in general. Time period, subsistence strategy and environment were found to be major factors impacting caries frequencies. Sex of individuals was found to have no statistically significant impact upon caries prevalence, though visuals show marked trends. Despite some of the results contradicting worldwide trends, the sample size, sheer scope of the study area, and reliability of the statistical tests give credibility to the findings.

7.2 Answer to overall hypothesis

The overall the null hypothesis proposed at the beginning of the thesis is rejected because statistically significant differences in caries frequencies were found to exist both among and between the variables. Each of the research questions were addressed and answered using various statistical analyses.

1. Did caries frequencies change through time? Major changes to the diet triggered by the Bantu Expansion and European contact caused a general increase in caries. New crops and soft processed foods proved beneficial to plaque-causing bacteria.

2. Is there a difference in dental decay between the sexes? Initial results showed that there is no statistically significant difference between males and females. However, upon further analysis statistically significant results show that more pastoral females have caries than their male counterparts. The gender division of labor and eating practices are possible explanations for

the differences in caries frequencies between males and females. There is no evidence that biological factors, such as hormone levels, affect caries prevalence.

3. Are there environmental differences in the frequency of caries throughout sub-Saharan Africa? Because crops are restricted by environmental conditions, caries are also influenced by where and when people lived. In particular, the southern coast and savanna regions promote dental decay either because of the lack of fluoride and/or dependence on foods high in carbohydrates.

4. Does subsistence strategy affect dental health? Statistically significant results indicate that subsistence strategy affects the frequency of carious lesions. Pastoralists might be more at risk because of increased milk consumption and high amounts of simple carbohydrates in the diet. Similarly, agriculturalists also eat a lot of simple carbohydrates and consequently have high caries counts. During the LSA hunter/gatherers and low amounts of caries but Recent hunter/gatherers rely on their neighbors for many food items, resulting in caries counts that are more similar to agriculturalists.

7.3 Future possibilities

Findings from the present study provide a foundation for future work. There is always the prospect of adding more individuals and samples. The larger the dataset, the more accurate the results. Another possibility would be to expand the current study to include caries location which can also aid in clarifying the composition of the diet (Hillson, 1996; 2001; Lanfranco and Eggers, 2010). Breaking down the adults into smaller categories can also prove helpful in determining patterns contingent on age since caries are an age-related disease. Furthermore, including additional dental pathologies, such as calculus, into the study could provide a pattern of dental diseases for various groups.

Overall, the best option would be to conduct similar studies for populations all over the world. As the current study's results show, not all populations follow the trends observed in other parts of the world or even within smaller subsets of the same sample. In order to get a true understanding of how caries work and what factors most contribute to their prevalence, each area has to be studied in turn. What applies to one region may not apply to another. The major advantage to dental pathology studies is to apply findings to an archaeological specimen(s) to learn more about their lifestyle. The best scenario would to compare any findings to an already existing data set from the same population.

7.4 Closing remarks

To conclude, dental decay in sub-Saharan Africans is closely related to their diet. For the past 10,000 years, diet has been subject to modification due to climate change, migration, diffusion, introduction of new crops, etc. Results obtained by factorial ANOVA found that environmental conditions and subsistence strategy were major contributors to caries frequencies. Mann-Whitney U and Tukey tests show statistically significant differences in caries among subsistence strategies and time periods. The results obtained demonstrate that worldwide trends do not always apply and that each population should be considered in turn. There is no denying the diversity of sub-Saharan people, and the present study provides a tool for interpreting their life history.

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APPENDIX A: DENTAL ATTRITION

Dental wear can be studied from three different viewpoints: macrowear, microwear, and wear patterns. Macrowear is tooth wear that can be seen with the naked eye and is generally the result of coarse particles in the food (Walker, 1978; Hillson, 1989). Comparing wear in different individuals or even populations is problematic because it is affected by age. Samples with different age profiles between group comparisons are very difficult and a more reliable analysis would be a comparison of inter-group variation (Scott and Turner, 1988).

There are several methods for recording dental wear (Hillson, 2008). Molnar (1971) encourages documenting both the direction of wear and the surface form of the tooth. Brothwell (1981) uses a five step wear progressive classification system starting at 0 (unworn) and ending at 4 (entire tooth crown lost and pulp cavity exposed).

The effects of agriculture on macrowear produce contrasting results. Molnar (1971) and Hinton (1981) found that hunter-gatherers generally have more wear because of the coarse unprocessed vegetation consumed. Conversely, Scott and Turner (1988) assert that agriculturalists have more wear due to processing techniques such as the use of grinding stones which add coarse particles to the food.

To observe microwear a scanning electron microscope (SEM) is used to examine the depth and relation of pits to scratches on a tooth (Teaford, 1991). Analyses can either be qualitative such as noting the presence or absence of pits, or quantitative where actual measurements are taken (Teaford, 1991). Interpretations can be used to show seasonal variations in diet (Teaford, 1991). White (2000) warns that microwear analyses might be too narrow and only show signs of the last meal or of only coarse foods thus not providing a true picture of the diet.

Finally, wear patterns can be measured using a modified protractor (Smith, 1984). These measurements can provide clues to an individual or a group's diet. For example, wear patterns can be used to determine the difference between agricultural or hunter-gatherer diets. Smith (1984) found that agriculturalists develop oblique wear which is attributed to the fact that they eat less tough foods as a result of food preparation. In contrast hunter-gatherers maintain relatively flat wear patterns (Smith, 1984).

In addition to diet, dental attrition can also be used to estimate age. This approach can be difficult because there are a lot of variables that can affect dental wear such as diet and sex. The method relies on the fact that as an individual gets older the more dental wear they will have. The two most commonly used methods for assessing age via attrition are credited to Brothwell and Miles (Walker et al, 1991; Roberts and Manchester, 2007). Brothwell's approach considers the amount of dentine visible and enamel worn away. Miles' approach also looks at exposed dentine but takes into account the eruption sequence of the teeth. For example M1 will show more wear than the other molars since it erupts and thus is exposed earlier. Other methods measure crown height rather than wear patterns. For example Tomenchuk and Mayhall (1979) used crown height when studying the correlation of wear and age in the Inuit. They found that there is a high correlation between age and wear and that males' teeth wear 30 percent faster than females'.

Dental attrition and its relation to diet have been extensively studied. A researcher can look at the teeth on a macro or micro level to determine diet and estimate age. Though there is still some debate as to the accuracy of some of these methods there is no doubt that dental attrition can greatly contribute to reconstructing the life history of an individual or eating patterns of a population.

APPENDIX B: GREENBERG'S AFRICAN LANGUAGE PHYLA

B.1 Introduction

Africa is one of the most linguistically diverse continents in the world with estimates of over 1000 spoken languages (Nurse, 1997; Campbell and Poser, 2008). Studies have found a positive relationship between physical characteristics or genetics to the four large African language phyla (Hiernaux, 1975; Exoffier et al., 1987). Often, especially in the case of sub-Saharan Africa other data such as archaeology are very limited; linguistics provides one alternative method for deciphering affinity and migration patterns.

In the 1950s Joseph Greenberg developed the most widespread and agreed upon language classification scheme (Heine and Nurse, 2000; Ehret, 2001, 2008; Campbell and Poser, 2008). His mass comparison method led him to organize all of Africa's' languages into four phyla: Afroasiatic, Nilo-Saharan, Niger Congo (originally Congo-Kordofanian), and Khoisan (Greenberg, 1970).

Despite the fact that the mass comparison method was very controversial at first, today it is used and widely supported (Heine and Nurse, 2000; Campbell and Poser, 2008). The method is overall advantageous because it considers many languages at once, not just two at a time like the traditional comparison method. In addition it excludes borrowers that often occur when considering a large number of words and languages that share geographical regions (Greenberg, 1970).

B.2 Afroasiatic

Afroasiatic languages are spoken in northern Africa and Asia (Figure 1); they will not be discussed as thoroughly as the other phyla because the scope of this study is limited to sub-Saharan Africa (Greenberg, 1970). Up to one third of African languages are Afroasiatic

(Hayward, 2000). Some of the world's better known civilizations were Afroasiatic speakers: the Egyptians, Assyrians, Phoenicians, Hebrews, and Arabs to name a few. Overall, the Afroasiatic phylum is the least contested, and ancient of Greenberg's language groups (Hayward, 2000; Campbell and Poser, 2008).

B.3 Niger-Congo

The Niger-Congo phylum is the largest in the world, making up the majority of languages in Africa including: Yoruba, Igbo, Fula, Shona, Zulu, and Swahili, which boast a combined 400+ million speakers (Williamson and Blench, 2000). Greenberg (1970) divided the Niger-Congo phylum into six sub-families: West Atlantic, Mande, Gur, Kwa, Benue-Congo, and Adamawa-Eastern. The majority of sub-Saharan Africa is inhabited by people who speak a Niger-Congo language (Figure 1). The most distinguishing features are noun prefixes, verbal extensions, and basic lexicon similarities (Greenberg, 1970; Nichols, 1997; Nurse, 1997; Campbell and Poser, 2000; Heine and Nurse, 2000).

The bulk of Niger-Congo speakers belong to the sub-group Benue-Congo (Bantu speakers) comprising around 450 languages (Holden, 2002). Major debates continue as to where the Bantu people came from, how their languages spread to cover most of sub-Saharan Africa, and how fast the languages spread. Greenberg was among the first to begin the discussion of a Bantu expansion, which has become one of the dominate topics in African linguistics (see below).

B.4 Nilo-Saharan

The Nilo-Saharan phylum, with an estimated 100 languages and around 50 million speakers is often referred to as Greenberg's wastebasket (Bender, 2000; Campbell and Poser, 2008). The Nilo-Saharan phylum is arguably one of the most disputed of all of Greenbergs' phyla because many believe the languages are largely unaffiliated and were combined merely because they did not fit in with any of the other phyla (Bender, 2000; Campbell and Poser, 2008). Bender (1997) states that “Nilo-Saharan is arguably the least-known of the four proposed African phyla, and the one for which the questions of integrity and composition are most open” (p.10). Originally, in 1955 Greenberg had sixteen genetic groups but in his revised 1966 classification he combined twelve of these into the Nilo-Saharan phyla, thus giving it a total of six branches (Greenberg, 1966).

Nilo-Saharan speakers live in the Sahara and northeastern Africa (Figure 1). The peoples practice many subsistence patterns, the most common of which today is agriculture, although several groups are pastoralists as well (Bender, 2000). In terms of ethnicity or “race” the Nilo-Saharan group consists of pygmy and tall (elongated) Africans (Irish, 1993; Bender, 2000).

Even though the phylum on a whole is problematic, most of the debate surrounding Nilo-Saharan lies with the Songhay branch (Campbell and Poser, 2008). Bender (1997) believes that Songhay actually belongs in the Niger-Congo phyla because it is more similar to Mande, a Niger-Congo branch. Geographically, Songhay is isolated from the rest of the Nilo-Saharan languages and exhibits influence from the Mande and Berber based languages (Bender, 2000).

Like the Khoisan phyla (below), the uncertainty of a genetic relationship within the Nilo-Saharan phyla is probably limited. However, the phyla as a whole can still be used to refer to the languages that do not have a close affiliation to any of the other phyla.

B.5 Khoisan

Khoisan languages make up the smallest of Greenberg’s four major African language phyla with a rough estimate of 200,000 speakers (Guldemann and Vossen, 2000). There are only about 30 languages scattered over eastern and southern Africa (Figure 1) that belong to the phylum (Guldemann and Vossen, 2000). Greenberg (1970) believed the Khoisan to be of great antiquity because of their fragmented distribution. As Bantu languages spread, the original languages of the area were either wiped out or absorbed except for a few groups. These remaining groups were clumped together by Greenberg (1970) to form the Khoisan phylum. Even today, the residual Khoisan languages are in jeopardy of becoming extinct due to new groups moving into the areas where Khoisan languages are still spoken (Guldemann and Vossen, 2000).

Khoisan languages are very unique because the click sound has morphological significance, meaning that the inclusion or exclusion of a click will change the meaning of the word. The unique click sounds have not been observed anywhere else in the world (Greenberg, 1950). Greenberg (1963) specifically defines Khoisan as “those African languages which use clicks as regular speech sounds and which are not obviously members of one of the other families” (p.66). Despite this unique feature, some researchers do not believe Khoisan to be a true genetic group but rather remnants of several different language families (Guldemann and Vossen, 2000; Campbell and Poser, 2008). Guldemann and Vossen (2000) argue that the lack of evidence to support a true language group is a result of, “the large proportion of missing links caused by the fact that too many of the extinct languages forever escaped our notice and that still too many of those which are alive have not been studied in detail” (p.99). Campbell and Poser (2008) argue that Greenberg violated his own principle by grouping the Khoisan languages together simply because of the presence of clicks. However, Greenberg emphasized the importance of including both sound and meaning in his methods (Greenberg, 1970). Even though the classification of this phylum is under scrutiny, many researchers still believe in combining the Khoisan languages to simply differentiate them from non-Bantu and non-Cushitic languages of eastern and southern Africa (Campbell and Poser, 2008).

There are four main populations today that make up the Khoisan phylum. The San (Bushman) and Khoikhoi (Hottentot or Khoe) are both in South Africa and are more closely related to each other than to the other two populations. The San are modern day hunter/gatherers who live in the Kalahari Desert; whereas, the Khoikhoi are pastoralists with a somewhat complex political organization and sense of ethnic distinctness (Greenberg, 1970). Originally, the Khoikhoi were categorized with the Hamitic groups by Meinhof in 1903 but Greenberg (1950) found that over 70% of their words had click sounds in them and that the Hamitic characteristics were borrowed (Greenberg, 1970).

The Sandawe and Hadza people are hunter-gatherers who live in eastern Africa and are probably closely related (Greenberg, 1970). Even though both groups use clicks in their language, their grammar and word structure clearly sets them apart from the Khoikhoi and San. The Sandawe are missing the tense particles which are seen in the other Khoisan groups and the Hadza have click sounds in the middle of their words instead of in the beginning (Greenberg, 1970).

B.6 Conclusion

Though there were many who attempted to organize and classify the African languages before and after his study, Greenberg's African language classification scheme is still the most complete and widely agreed upon. His four phyla, consisting of the northern Afroasiatic, widespread Niger-Congo, variable Nilo-Saharan, and unique- sounding Khoisan provide an easy way to refer to linguistically related peoples. Greenberg's methods and results have been heavily scrutinized but there is no doubt that the African language phyla have been incredibly useful for various reasons in many research fields.

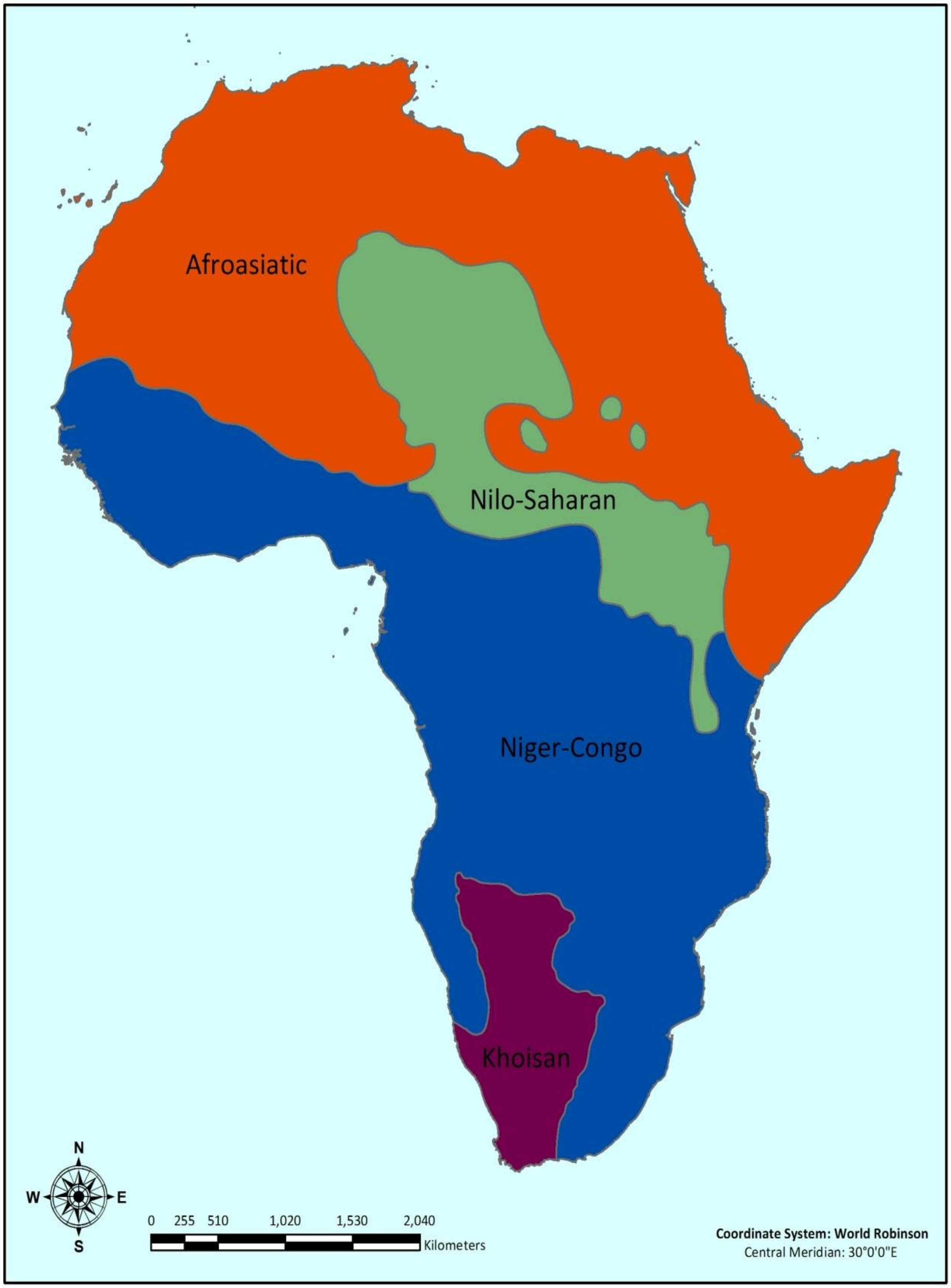

Figure B-1: Map of Greenberg's language phyla (modified from Collins and Burns, 2007, p.45 with ArcGIS9, 2009)

APPENDIX C: BANTU EXPANSION METHODS OVERVIEW

Two main linguistic models are widely used in the literature to make inferences about Bantu-speaking peoples. The tree model emphasizes migration and deviation from the mother language (Afolayan, 2000). Because the model is often represented in tree form, abrupt branches imply quick changes in the language. This model is problematic when applied to Bantu because evidence indicates that the languages underwent gradual change (Ehret, 2001). Also, the tree model does not allow for simultaneous splitting of more than one language (Afolayan, 2000). Such a handicap can greatly affect interpretations of Bantu changes. The languages probably underwent several splits, and most likely some occurred at the same time. Even with these complications the tree model should not be dismissed, as a modified tree model could account for these discrepancies (Ehret, 2001).

The wave model is based on differentiating clusters to make inferences about language progression. It also takes into account merging languages (Afolyan, 2000). The pitfall to this model is that other features are also combined with nothing to distinguish them from other factors (Ehret, 2001). For instance, borrowed words are often grouped with inherited words. Because a major contribution to the variation in Bantu languages is due to borrowed words, especially from the original populations, this model is probably not the best to apply to the Bantu Expansion.

Where linguistics can provide models for possible migration, archaeology provides evidence for the enablers that made such migrations possible. However, archaeological evidence for sub-Saharan Africa is severely lacking (Phillipson, 2005). Geographical and temporal gaps in the archaeological record make trends difficult to observe. The lack of data is not the fault of archaeologists, but rather taphonomy, space, and politics.

Because the proto-Bantu language speakers resided in forests, where soil acidity is high, few cultural materials survived. The soils dissolve all but the sturdiest materials (Lyman, 1994). Only the presence of materials such as stone, iron, and maybe bone in the archaeological record has created a strong bias in analyses and interpretations. Another factor affecting Bantu archaeology is that there are not enough archaeologists to examine the region in depth. Finding a site is a mixture of luck, determination, and knowledge. Finally, Africa is plagued by political strife. During such times, it may not safe for any archaeological work to be conducted (Phillipson, 2005). The limited amount of archaeological evidence supports linguistic models of the Bantu Expansion (Posnansky, 1968; Soper, 1982; Afolayan, 2000; Phillipson, 2005).

Applications of physical anthropology to examine the Bantu language dispersal are rare. Gene flow between close geographical populations is problematic for comparing physical characteristics. The high degree of admixture with other groups results in a general uniformity of features with adjacent populations. Irish's (1997) study of dental morphology of sub-Saharan populations shows such a trend. Though the morphology of sub-Saharan population teeth is very distinct from other world populations, including northern Africa, there is little variation within the group. Hiernaux (1968) states that if there are any differences among sub-Saharans it would be in the southern Bantu because of their admixture with the Khoisan-speaking people.

Molecular anthropologists have recently jumped into the Bantu Expansion debate. Within the past few years valuable information has been obtained concerning marriage patterns, mode, and size of the Bantu Expansion (O'Rourke et al., 2000; Salas et al., 2002; Wood et al., 2005; Gonder et al., 2006; Mulligan, 2006; Garrigan et al., 2007; Scheifeldt et al., 2010; de Filippo et al., 2011; Pakendorf et al., 2011; Siren et al., 2011). Molecular anthropology studies for sub-Saharan groups are relatively sparse (Pakendorf et al., 2011). Despite the incorporation of molecular anthropology into the Bantu Expansion discussion and all of its exciting new finds, no analysis conclusively proves or disproves migrations patterns (Pakendorf et al., 2011). There are still too much missing data to make any definitive conclusions (Pakendorf et al., 2011).

APPENDIX D: DESCRIPTIVE GRAPHS

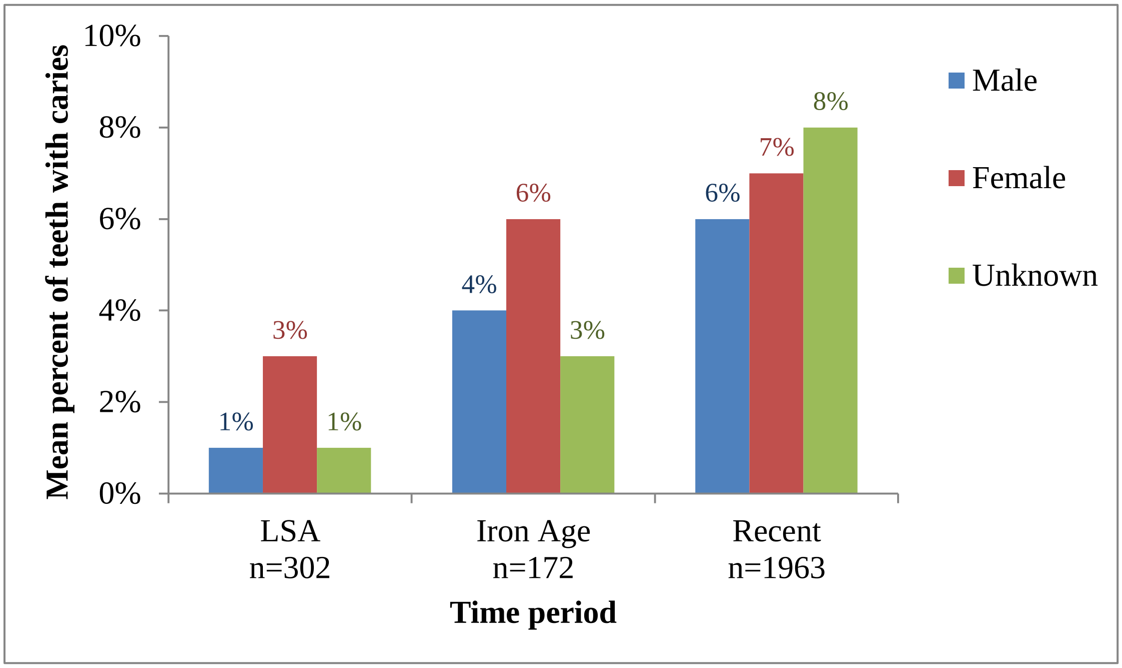

Figure D-1: Mean percent of teeth affected by caries for males, females, and individuals of unknown sex for each time period

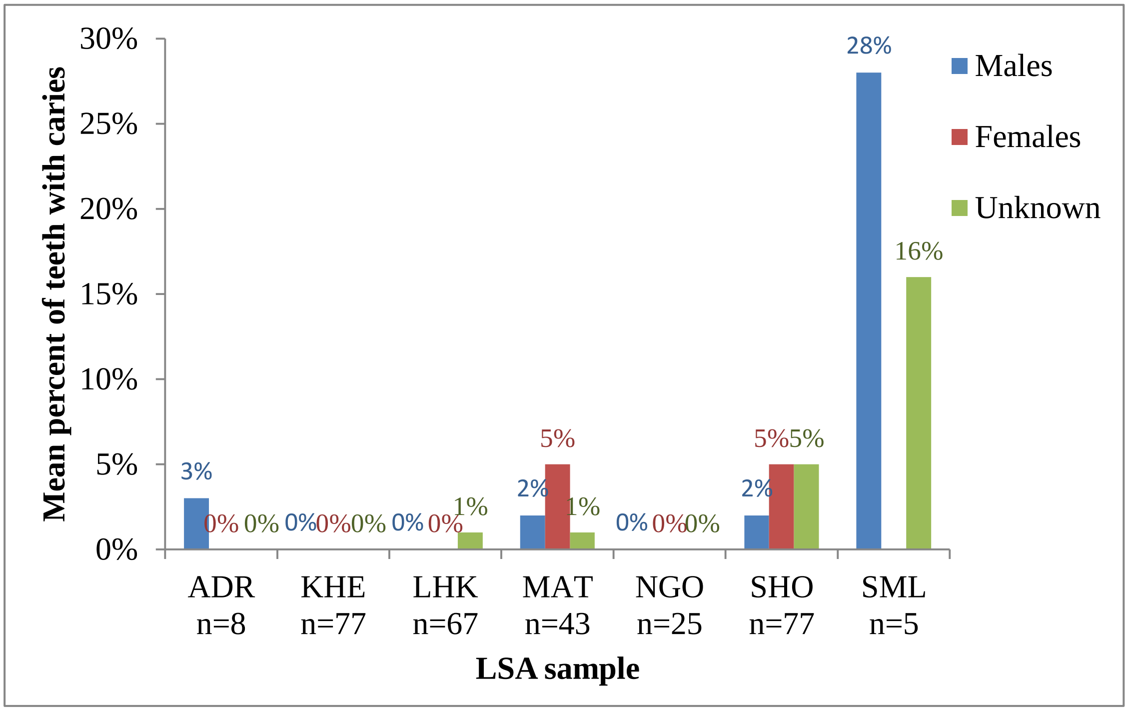

Figure D-2: Mean percent of teeth affected by caries for LSA males, females, and individuals of unknown sex

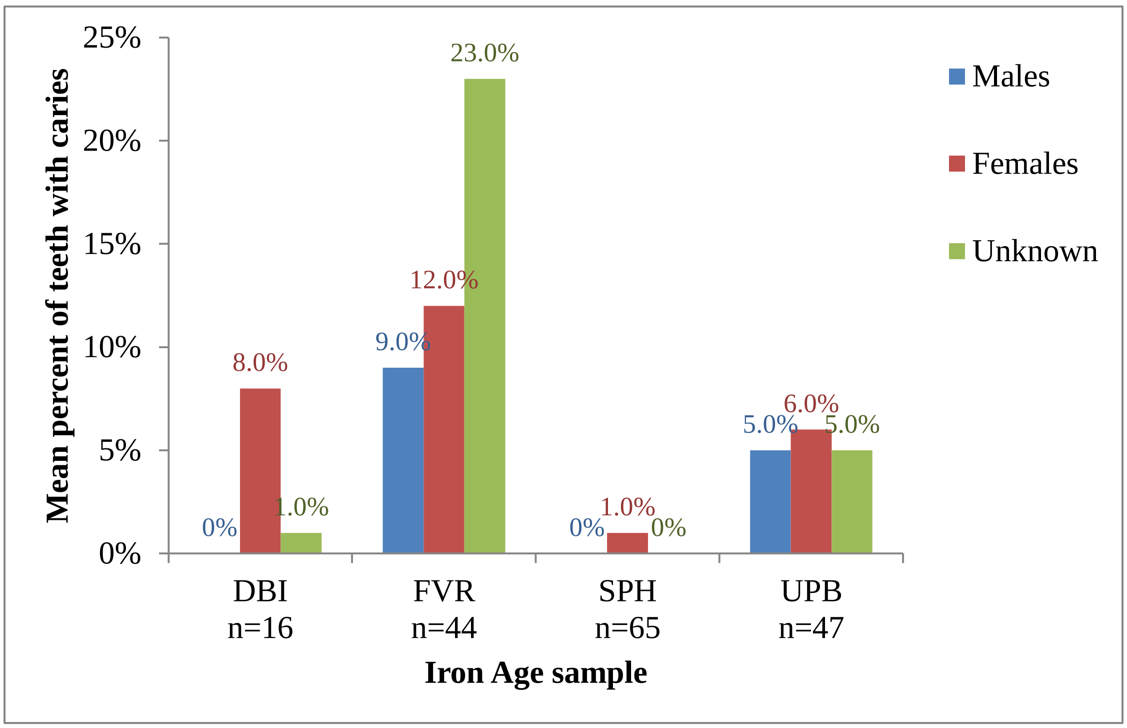

Figure D-3: Mean percent of teeth affected by caries for Iron Age males, females, and individuals of unknown sex

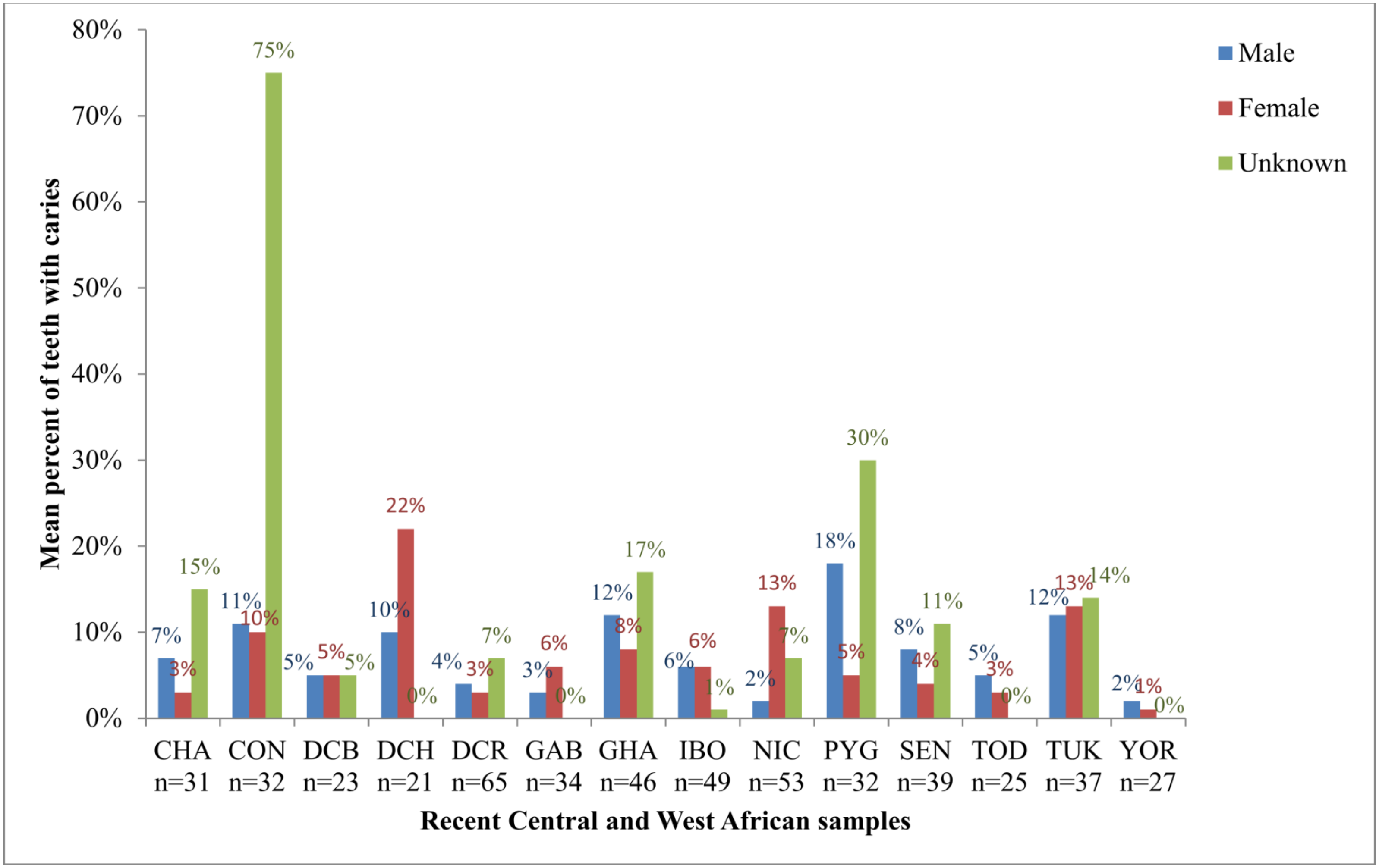

Figure D-4: Mean percent of teeth affected by caries for Recent central and West African males, females, and individuals of unknown sex

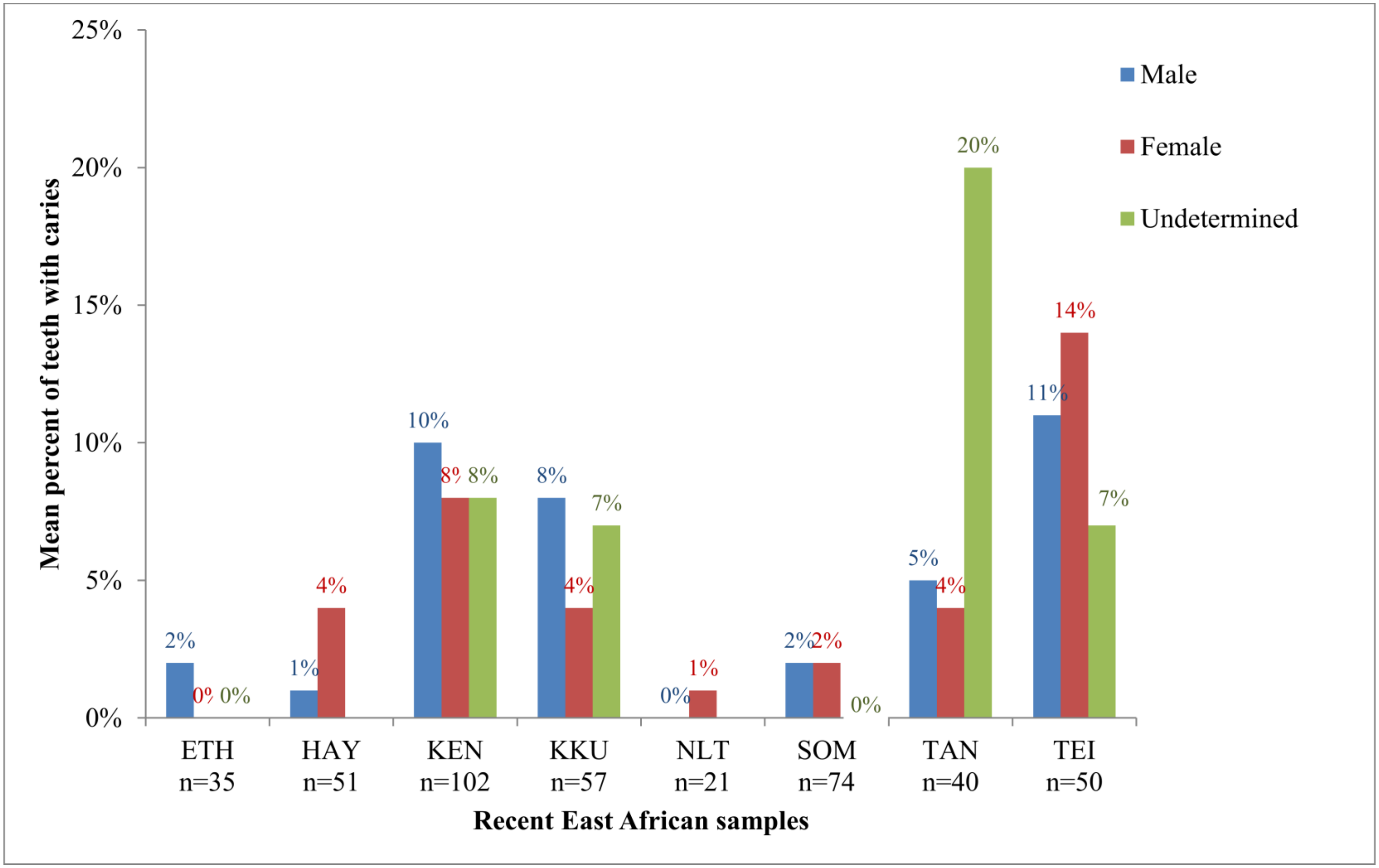

Figure D-5: Mean percent of teeth affected by caries for Recent East African males, females, and individuals of unknown sex

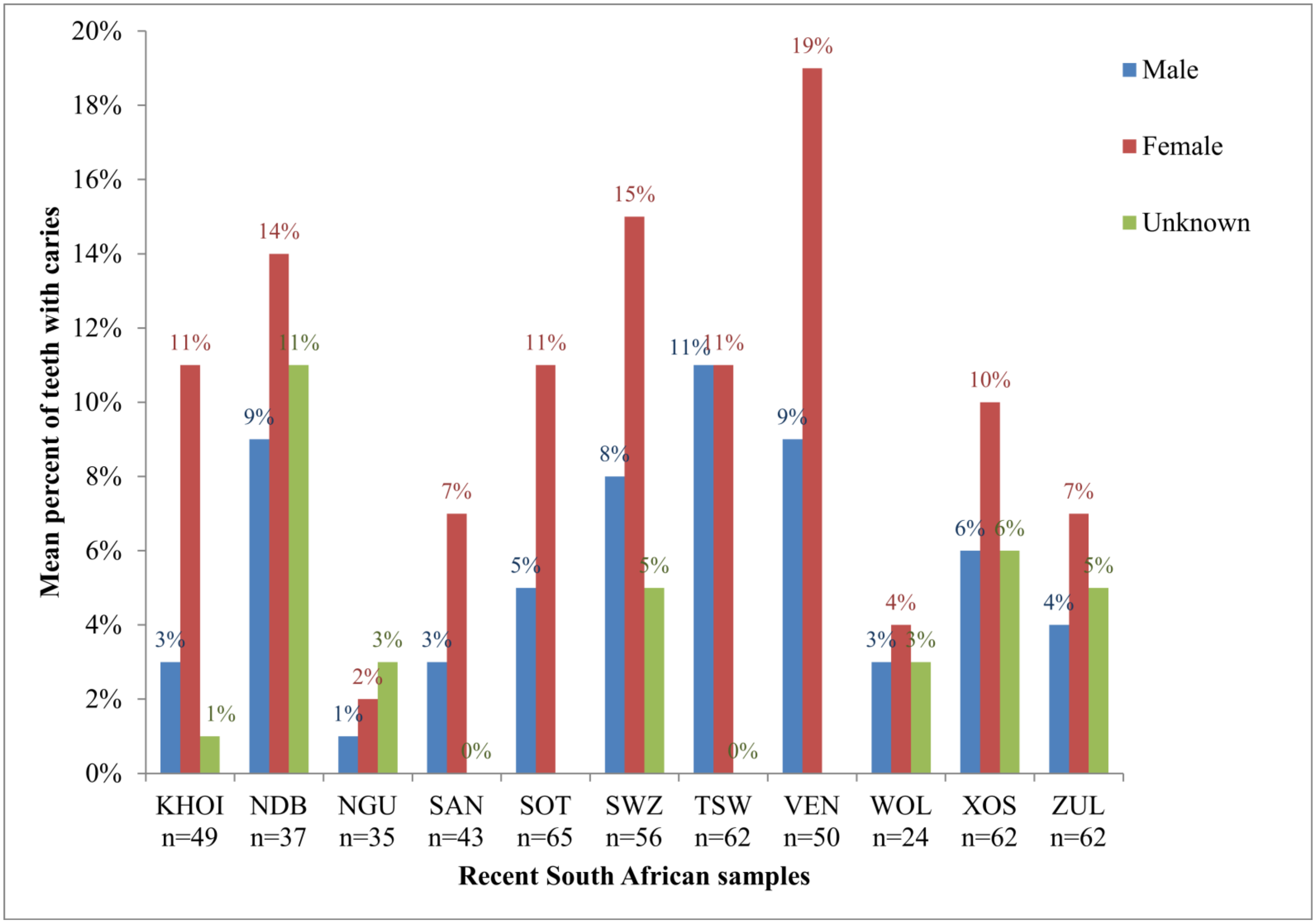

Figure D-6: Mean percent of teeth affected by caries for Recent South African males, females, and individuals of unknown sex

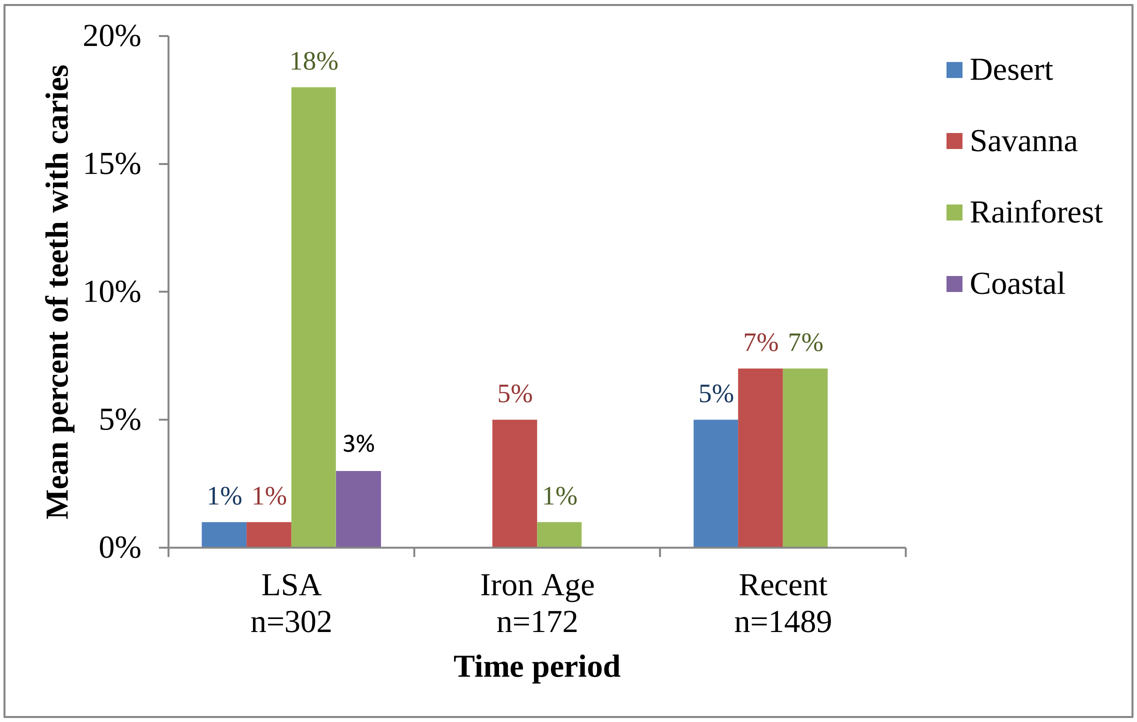

Figure D-7: Mean percent of teeth affected by caries for each environment during the LSA, Iron Age, and Recent

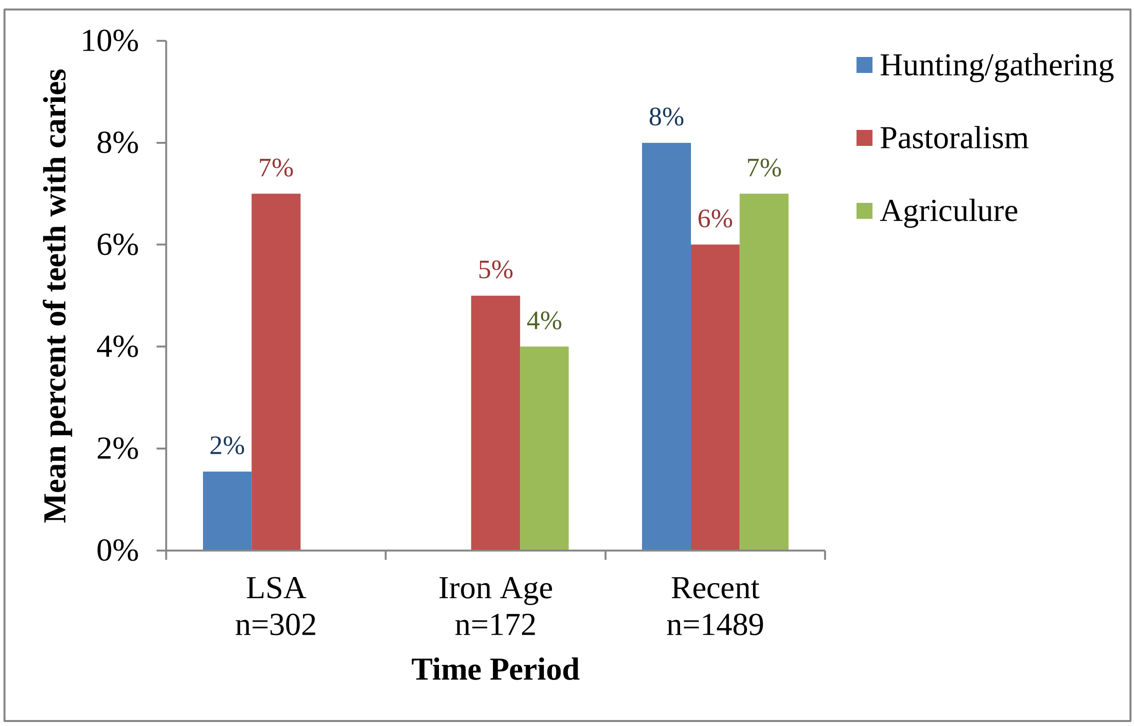

Figure D-8: Mean percent of teeth affected by caries for each subsistence strategy during the LSA, Iron Age, and Recent

APPENDIX E: TEST FOR FACTORIAL ANOVA ASSUMPTIONS

Table E-1. Lavene's test
Significance = 0.00

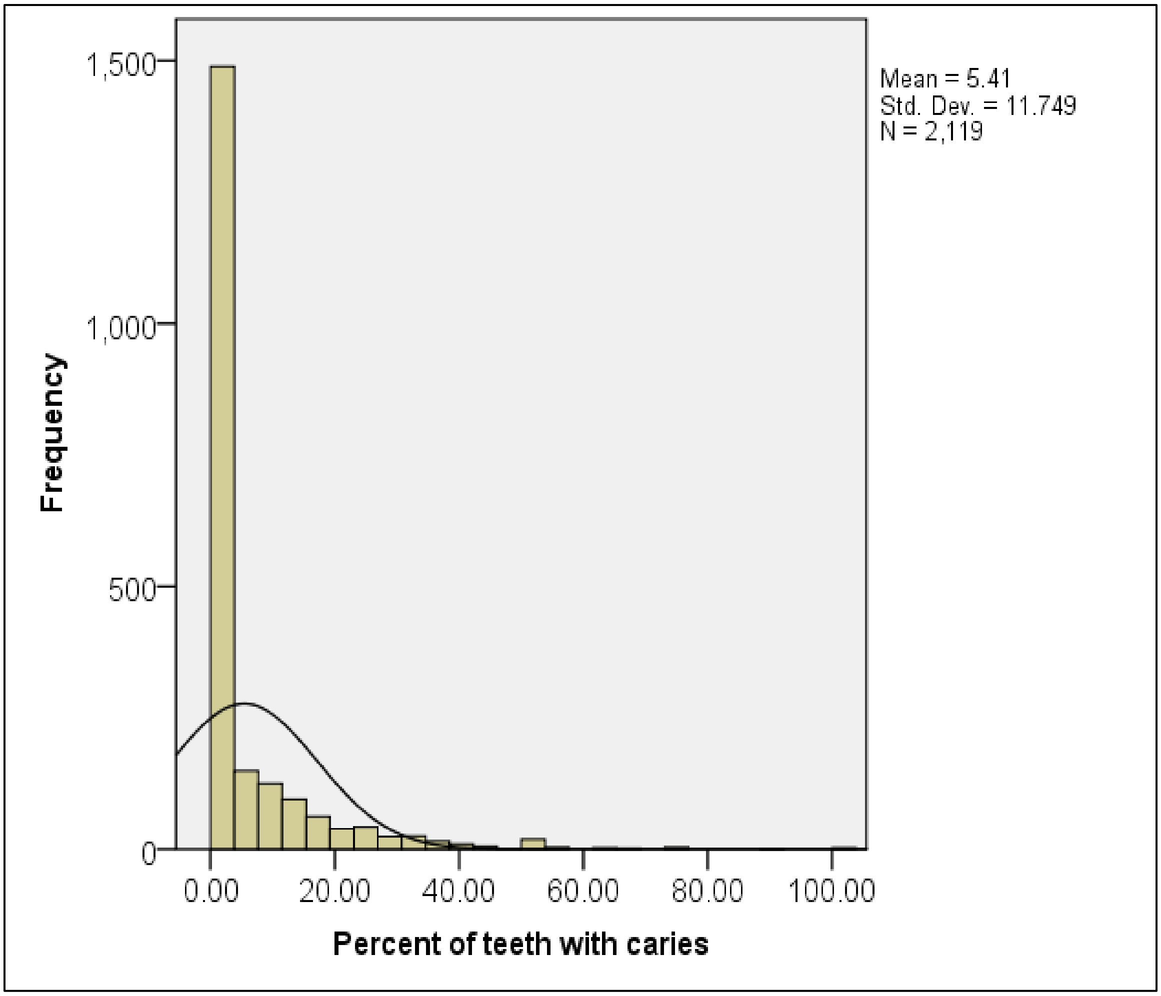

Figure E-1. Histogram showing the distribution for the percent of teeth with caries

APPENDIX F: INDEPENDENT T-TEST RESULTS

Table F-1. Independent t-test

		Significance			
Variable	**Groups**	**LSA**	**Iron Age**	**Recent**	**Combined**
Time Period	LSA & Iron Age	n/a	n/a	n/a	0.005
	LSA & Recent	n/a	n/a	n/a	0.000
	Iron Age & Recent	n/a	n/a	n/a	0.012
Sex	Male & Female	0.137	0.260	0.153	0.274
Environment	Desert & Savanna	0.111	n/a	0.059	0.542
	Desert & Rainforest	0.136	n/a	0.296	0.206
	Desert and Coastal	0.225	n/a	n/a	0.034
	Savanna & Rainforest	0.000	0.185	0.513	0.354
	Savanna & Coastal	0.044	n/a	n/a	0.003
	Rainforest & Coastal	0.000	n/a	n/a	0.002
Subsistence	Hunting/Gathering & Pastoralism	0.000	n/a	0.224	0.000
	Hunting/Gathering & Agriculture	n/a	n/a	0.059	0.000
	Pastoralism & Agriculture	n/a	0.727	0.516	0.046